Quivira Tronox Mine Site
Navajo Nation, New Mexico

Draft
Alternatives Analysis

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TETRA TECH

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ACRONYMS AND ABBREVIATIONS

95UCL	95th percentile upper confidence limit
AAM	Alternatives Analysis Memorandum
ARAR	Applicable or relevant and appropriate requirement
ASTM	ASTM International
AUM	Abandoned uranium mine
bgs	Below ground surface
BIA	Bureau of Indian Affairs
BLM	Bureau of Land Management
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	*Code of Federal Regulations*
CO_2e	Carbon dioxide equivalent
COC	Contaminant of concern
COEC	Contaminant of ecological concern
COPC	Contaminant of potential concern
CR-1	Quivira Tronox Church Rock #1 Mine Site
CR-1E	Quivira Tronox Church Rock #1E Mine Site
CR-2	Quivira Tronox Church Rock #2 Mine Site
CRA	Conestoga Rovers and Associates Ltd.
cy	Cubic yards
DCGL	Derived concentration guideline level
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
DRO	Diesel-range organics
DRUM	Defense-Related Uranium Mine
E&E	Ecology and Environment, Inc.
EcoSSL	Ecological Soil Screening Level
EERG	Engineering/Remediation Resources Group, Inc.
EIS	Environmental Impact Statement
ESL	Ecological screening level
ET	Evapotranspiration
gpm	Gallons per minute
GSA	Geographic Sub-Area
HDPE	High-density polyethylene
HELP	Hydrologic Evaluation of Landfill Performance
HI	Noncancer hazard index
HQ	Hazard quotient
IC	Institutional control

Kerr-McGee	Kerr-McGee Corporation
LANL	Los Alamos National Laboratory
LLRW	Low-level radioactive waste
MARSSIM	*Multi-Agency Radiation Survey and Site Investigation Manual*
mg/kg	Milligrams per kilogram
MWH	Montgomery Watson Harza
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NECR	Northeast Church Rock
NMED	New Mexico Environmental Department
NNEPA	Navajo Nation Environmental Protection Agency
NORM	Naturally occurring radioactive material
NPDES	National Pollutant Discharge Elimination System
NPV	Net present value
NRC	U.S. Nuclear Regulatory Commission
O&M	Operation and maintenance
OMB	Office of Management and Budget
OSHA	Occupational Safety and Health Administration
OSWER	Office of Solid Waste and Emergency Response
pCi/g	Picocuries per gram
pCi/L	Picocuries per liter
PRSC	Post-removal site control
Ra-226	Radium-226
Ra-228	Radium-228
RAG	Remedial action goal
RAML	Rio Algom Mining LLC
RAO	Removal action objective
RCRA	Resource Conservation and Recovery Act
RSE	Removal site evaluation
RSL	Regional screening level
SENES	SENES Consultants Limited
Site	Quivira Tronox Mine Site
SPLP	Synthetic precipitation leaching procedure
TBC	To be considered
TCLP	Toxicity characteristic leaching procedure
TCRA	Time-critical removal action
TENORM	Technologically enhanced naturally occurring radioactive material
TPH	Total petroleum hydrocarbons

U-235	Uranium-235
U-238	Uranium-238
U_3O_8	Triuranium octoxide
UO_2	Uranium dioxide
UMTRCA	Uranium Mill Tailings Radiation Control Act
UNC	United Nuclear Corporation
USCB	U.S. Census Bureau
USEPA	U.S. Environmental Protection Agency
Weston	Weston Solutions, Inc.

1.0 EXECUTIVE SUMMARY

1.1 PURPOSE OF AAM

The United States Environmental Protection Agency (USEPA) prepared this Engineering Evaluation/Cost Analysis (AAM) Report regarding the Quivira Tronox Mine Site (Quivira Mines, or the Site) near Gallup, New Mexico, in the Navajo Nation. The purpose of this AAM is to evaluate alternatives to address human and ecological health risks at the Site. In this document, "the Site" is defined as CR-1 and CR-1E, and the Kerr McGee Ponds (Figure 1).

1.2 SITE CHARACTERIZATION

The Quivira Tronox Church Rock #1 Mine Site (CR-1) and the Quivira Tronox Church Rock #1 East Mine Site (CR-1E) were leased for underground mining operations between about 1972 and 1986. A third leased site, Quivira Tronox Church Rock # 2 Mine Site (CR-2) was about 1.5 miles northwest of CR-1, but CR-2 was never developed, and an investigation found no evidence of environmental impacts from mining there. The mines at CR-1 and CR-1E are on Navajo Nation lands, approximately 20 miles northeast of the City of Gallup, New Mexico (Figure 1). Access to the area is via New Mexico Highway 566. The Navajo Nation Chapters of Coyote Canyon, Nahodishgish, Standing Rock, Pinedale, and Church Rock intersect nearby. Shafts were sunk at CR-1 and CR-1E, and ore was extracted from approximately 1,800 feet below ground surface (bgs).

Except for remnants of former mine operations and reclamation, the Site currently is undeveloped, although livestock grazing occasionally occurs on both CR-1 and CR-1E. Land use in the area is mainly low-density, single-family residential and open grazing, with some gathering of traditional plants and herbs. Several residences are within about 0.5 mile of CR-1 or CR-1E. Continuation of current land uses is expected for the foreseeable future. Nearby residents and livestock could be exposed to contaminants at the Site via incidental ingestion of soil, external radiation from contaminants, inhalation of fugitive dusts, and/or meat and plant consumption.

In November 2014, the U.S. District Court for the Southern District of New York approved a settlement agreement to resolve fraudulent conveyance claims against Kerr-McGee Corporation (Kerr-McGee) and related subsidiaries of Anadarko Petroleum Corporation. Included in the settlement were funds for assessment and remediation of the Quivira Tronox Mine.

1.3 REMOVAL ACTION OBJECTIVES

The main objectives of this removal action are to:

- Prevent exposure to soil containing contaminants at levels above background concentrations and above concentrations that would pose an unacceptable risk to human health with residential use and traditional Navajo lifeways outside of any potential capped area.
- Prevent exposure to soil containing contaminants at levels above background concentrations and above concentrations that would pose an unacceptable risk to human

health with traditional Navajo lifeways on any potential capped area. This may include exposures during activities such as livestock grazing, hunting, and plant gathering and use.

- Prevent exposure to soil containing contaminant levels above background concentrations and above concentrations that would pose an unacceptable risk to plants, animals, and other ecological receptors.
- Prevent migration to groundwater of contaminants at levels above background concentrations and above concentrations that pose an unacceptable risk to human health.
- Prevent off-site migration of contaminants at levels above background concentrations and at concentrations that could pose a risk to human health or the environment.

Options to be analyzed include response actions that would allow unrestricted residential and Navajo lifeways use, as well as response actions that would include land use restrictions limiting residential use and uncontrolled grazing on portions of the Site. The intent of the response action is to address the surface and subsurface contaminated soils/debris at CR-1 and CR-1E.

1.4 IDENTIFICATION OF REMOVAL ACTION ALTERNATIVES

The following response alternatives were considered as part of this AAM. Alternative 4 is still under development pending finalization of a regional repository location. Each alternative was evaluated against the criteria of effectiveness, implementability, and cost.

Alternative 1: No Action.

Alternative 2: Consolidate and Cap All Waste at CR-1.

Alternative 3: Consolidate and Cap All Waste Separately at CR-1 and CR-1E.

Alternative 4: Reprocess or Dispose of All Mine Waste Off Site at a Licensed/Permitted Facility.

1.5 ANALYSIS OF REMOVAL ACTION ALTERNATIVES

The alternatives were evaluated according to the criteria of effectiveness, implementability, and cost.

Effectiveness

After site restoration and revegetation, the Site would be suitable for unrestricted residential and grazing use under Alternative 4. Under Alternatives 2 and 3, unrestricted residential use would be allowed at the Site except for restrictions within portions of the Site occupied by the repository(ies) and where waste would have been removed. Nearby residents and future on-site visitors would be protected under all alternatives except Alternative 1 (No Action). Grazing use may or may not be limited under Alternatives 2 and 3 based on (1) whether over-grazing occurs, facilitating erosion or negatively affecting vegetation; and (2) cover maintenance requirements.

Except for the No Action alternative, all the alternatives would protect human health and the environment.

Alternatives 2, 3, and 4 all comply with applicable or relevant and appropriate requirements (ARARs) and are equal under this criterion. ARARs pertain only to actual response actions and are not applicable to Alternative 1.

Short-term effectiveness is rated good under Alternatives 2 and 3, based on less handling and transportation of contaminated material than under Alternative 4 and shorter time for completion. Short-term effectiveness is rated poor to very poor under Alternative 4 because all the soil must be excavated and loaded in trucks, with a high number of trucks driving through Navajo communities to transport the waste. Alternative 4 also poses increased risks of injury to workers, of traffic accidents, and of increased carbon footprint.

Alternative 4 is rated very good for long-term effectiveness because the waste would be managed at a geologically stable location away from communities. Alternatives 2 and 3 are rated good for long-term effectiveness and permanence. Although waste would be managed in an engineered capped area, under each of these alternatives, maintenance of the cover would be required.

Implementability

All alternatives except Alternative 1 (No Action) are implementable via conventional techniques, materials, and labor. Alternatives 2 and 3 are rated good for implementability because the local construction would require no permits, but would necessitate the most stakeholder engagement for on-Navajo Nation repositories. Alternative 4 is rated good to very good because managing waste at a licensed facility is well established but would require permits for hauling.

Cost

In evaluations of cost, alternatives with higher costs have lower cost ratings. Costs under Alternative 4 are rated poor to very poor. The least costly and highest-rated alternatives are Alternatives 2 and 3.

Exhibit 1 below summarizes the ratings for effectiveness, implementability, and cost for each alternative.

1.6 RECOMMENDED REMOVAL ALTERNATIVE (OMITTED IN AN AAM)

Input from the communities, Navajo Nation, State of New Mexico, and other stakeholders may include information not considered by USEPA in this AAM, and may change the ratings of the Alternatives with respect to one another. This document is a draft and does not select a preferred alternative. USEPA will select an alternative for the final action after considering input from the communities, Navajo Nation, the State of New Mexico, and other stakeholders.

Exhibit 1. Summary of Alternative Ratings

Alternative	Effectiveness	Implementability	Cost Rating
1 No Action	Short-Term: Very Good Long-Term: Very Poor	Very Good	Very Good
2 Consolidate and Cap All Waste at CR-1	Short-Term: Good Long-Term: Good	Good	Good
3 Consolidate and Cap all Waste Separately at CR-1 and CR-1E	Short-Term: Good Long-Term: Good	Good	Average
4 Process/Dispose of All Waste Off Nation at Licensed/Permitted Facility	Short-Term: Poor to Very Poor Long-Term: Very Good	Good to Very Good	Poor to Very Poor

2.0 SITE CHARACTERIZATION

Multiple investigations have occurred to characterize the Site (CR-1, CR-1E, and the Kerr McGee Ponds). CR-2, previously addressed, is not included in this AAM.

2.1 SITE DESCRIPTION AND BACKGROUND

The Quivira Mines are on Navajo Nation lands, approximately 20 miles northeast of the City of Gallup, New Mexico (Figure 1). Access to the area is via Highway 566. The Navajo Nation Chapters of Coyote Canyon, Nahodishgish, Standing Rock, Pinedale, and Church Rock are nearby. The Site description is based in part on the Quivira Mines Expanded Site Screening Report (Weston Solutions, Inc. [Weston] 2010), the Phase 2 Removal Evaluation Work Plan for CR-1 and CR-1E (SENES Consultants Limited [SENES] 2010), and the Removal Site Evaluation (RSE) Report regarding CR-1 and CR-1E (SENES 2011). Additional information about the nearby Northeast Church Rock (NECR) Mine and United Nuclear Corporation (UNC) Mill was obtained from the NECR Mine Site Assessment (Montgomery Watson Harza [MWH] 2003), the NECR AAM (USEPA 2009a), the UNC Superfund Site Surface Soil Operable Unit Proposed Plan (USEPA 2012a), and the UNC Superfund Site Record of Decision (USEPA 2013).

CR-1

CR-1 includes a former industrial area, a waste rock area, and a former pond area (Figure 2). Geographic coordinates at the center of CR-1 are 35° 39' 55.6" latitude and -108° 30' 3.5" longitude. CR-1 is along Red Water Pond Road, north of New Mexico Route 566. CR-1 encompasses a surface area of 42 acres, with approximately 6.4 million square feet of underground workings extending toward the CR-1E mine (Weston 2010). The industrial area is defined by the portion of CR-1 where industrial buildings and ancillary structures were located.

The buildings have been razed and the area graded. According to the Phase 2 Removal Evaluation Work Plan for CR-1 and CR-1E (SENES 2010), uranium ore was hoisted to surface at CR-1 via a shaft and temporarily stockpiled prior to truck haulage to the Quivira Ambrosia Lake milling operation. A number of surface structures existed during the operating years, including a shaft collar and head frame, ventilation raises, and ore stockpile area; office, hoist house, maintenance shops, and warehousing complex; mobile equipment repair shop; fuel and oil storage facilities; main electrical transformer and switch gear; explosive storage area; and internal roads and water drainage to divert water from the waste areas and rock storage areas (SENES 2010).

The waste rock pile is on the western and southern portion of CR-1, adjacent to Red Water Pond Road to the west and Unnamed Arroyo #2 to the south (Figure 2). The waste rock pile has a 30- to 40-foot face that is generally sloped 3H:1V. Most of the waste rock material within the stockpile is fine-grained—fine to medium sand with little to no coarse sand or gravel.

A water production well, installed at approximately 1,800 feet bgs, was used to dewater the mine workings during operations (USEPA 2010b). Mine water was pumped to the surface and

discharged to a series of nine holding ponds for settling of solids and treatment prior to release into the Unnamed Arroyo #2.

CR-1E

The former industrial area is the portion of CR-1E previously occupied by industrial buildings and ancillary structures. The buildings were razed at closeout of operations, and most of the area has been covered with soil and rock. Two small, soil-covered waste rock stockpiles only slightly above grade in height are in the north-central portion of CR-1E. Most of the waste rock material within the stockpile is fine to medium sand with little to no coarse sand or gravel. The former pond area is a small area where historical aerial photographs depict construction and use of a sediment pond in the mining operations. Locations of CR-2 and Quivira Vent Holes 1 through 4 are shown on Figure 1.

Kerr McGee Ponds

In early 2017, USEPA became aware that Kerr-McGee had operated a sediment pond and an ore storage area on land leased from the State of New Mexico approximately 2,000 feet south of CR-1E (Figure 4). In addition, office space and a training facility had been located nearby. Reportedly, the various work areas were closed when the state transferred the land at the mill to UNC. Preliminary assessment work during summer 2017 indicated presence of elevated gamma activity in surface soils.

2.1.1 Type of Mine and Operational Status

The surface estate of the Quivira Mines is owned by the United States in trust for the Navajo Nation, and is part of the Navajo Nation Reservation (USEPA 2012a). The land was leased for mining from the Bureau of Indian Affairs (BIA) as owner of the mineral estate under the Navajo Tribal Uranium Leases 14-0-0603-9987 (CR-1) and 14-20-0603-9988 (CR-1E). Kerr-McGee conducted exploration and development of CR-1 and CR-1E from the late 1960s into early 1986 (SENES 2010). Kerr-McGee and then its subsidiary, Kerr-McGee Nuclear, which later changed its name to the Quivira Mining Corporation, began development of the mines in 1974 and produced ore from approximately 1974 until 1986 (CR-1) and from 1976 until 1985 (CR-1E). Kerr-McGee also operated a sediment pond and an ore storage area on land leased from the State of New Mexico approximately 2,000 feet south of CR-1E. Quivira Mining Company surrendered the leased properties in February 1987. Quivira Mining Company was subsequently sold to the predecessor company of Rio Algom Mining LLC (RAML) in 1988 (SENES 2011).

Atomic Energy Commission records indicate production of 3,139,784 pounds of uranium (triuranium octoxide [U_3O_8]) from the CR-1 mine, and 1,447,463 pounds of U_3O_8 from the CR-1E mine during operation (Weston 2010). Uranium ore from the mines was processed at the Quivira Mining Corporation's Ambrosia Lake Mill approximately 50 miles to the east, north of Grants, New Mexico.

2.1.2 Regulatory History

Following cessation of operations at CR-1 and CR-1E in 1985 or 1986, the sediment ponds were scraped and filled, and wastes were consolidated at one location at each leased site. The wastes

(mainly waste rock and low-grade ore) were capped with 6 to 12 inches of fill material. Erosion and a general lack of maintenance have degraded the CR-1 cap. At CR-1, the wastes are in stockpiles as high as 50 feet above the original grade, with steep slopes along the margins. Estimated volume of the CR-1 waste pile and former sediment ponds is 810,000 cubic yards (cy). Wastes at CR-1E are below the surrounding land grade (rather than in an above grade pile), and erosion is not significant. Estimated volume of waste at CR-1E including the waste rock, former pond, and industrial and step-out areas is approximately 103,000 cy.

Between 2010 and 2018, contaminated soils were removed from Red Water Pond Road and from around five former ventilation shaft locations (Vent Hole 1 through Vent Hole 5), and were consolidated onto the CR-1 waste pile. The vents had been capped with 4-foot-thick concrete pads when the mines were closed, and the caps were left in place. In addition to soil removal, RAML and USEPA have reconstructed portions of Red Water Pond Road, and USEPA repaired the bridge near the CR-1 waste pile.

The nature and extent of the contamination at CR-1 and CR-1E were delineated via gamma scans and soil sampling and analysis. Based on results of the scans and from the samples, most of the waste is within the fenced areas at CR-1, and CR-1E. Based on results of the human and ecological risk assessments of the Site, the contaminants of concern (COCs) are arsenic and uranium and its decay products, including radium-226 (Ra-226). The risk assessment considered exposures for a Navajo traditional lifestyle, and established action levels of 2.0 picocuries per gram (pCi/g) for Ra-226, 16 milligrams per kilogram (mg/kg) for uranium, and 4.5 mg/kg (background) for arsenic. However, these action levels are being reevaluated, and updates to them will appear in a future version of this document.

The estimated total volume of soil containing COC concentrations exceeding action levels is 913,000 cy.

2.1.3 Site Features and Landscape

CR-1 is along Red Water Pond Road on the northern side of an arroyo at the base of a mesa, as shown on Figure 2. CR-1 previously was reclaimed after mining. Current features there include a large, covered waste pile that abuts the sandstone of the mesa to the north, with the former ponds area to the east. The pile and ponds areas are fenced.

Another reclaimed waste pile at CR-1E is 3,000 feet east of CR-1 (Figure 3). The pile is bounded by Pipeline Canyon Road and an arroyo to the east, and pushes up against sandstone cliffs on the north and west.

The Kerr McGee Ponds (Figure 4) are within a flat fenced area on an alluvial terrace in Pipeline Canyon approximately 0.5 mile south of CR-1E.

2.1.4 Geology and Hydrology

Geology

CR-1 and CR-1E lie in the Church Rock Mining District of the Grants Uranium Belt within the San Juan Geologic Basin. The San Juan Basin encompasses over 26,000 square miles of a bowl-

shaped depression of sedimentary rock ranging in age from approximately 2 million to 570 million years old. The sedimentary rock layers within the San Juan Basin dip (slope down) toward the center of the basin from the highlands at the margins. Older sedimentary rocks are exposed at the margins of the basin and are successively overlain by younger layers of rock toward the center (Brister and Hoffman 2002).

Sedimentary deposition occurred through cycles of marine, coastal, and nonmarine deposition from approximately 330 million to 2 million years ago (Pennsylvanian through Tertiary periods). The oldest of the sedimentary deposits consist of limestone, shale, sandstone, and gypsum of the Pennsylvanian and Permian formations, and serve as fractured groundwater aquifers in the Zuni uplift region east of Gallup. The Pennsylvanian and Permian rocks are overlain by non-marine sandstone, siltstone, and mudstone of the Chinle Group and the Rock Point Formation, and cross-bedded layers of sand in the Middle Jurassic Entrada Sandstone (Brister and Hoffman 2002).

The Entrada Sandstone is overlain by the Morrison Formation deposited during the Late Jurassic period (approximately 145 million years ago). The Morrison is one of several well-known uranium-bearing rock units in the Church Rock Mining Districts (Brister and Hoffman 2002). Three members of the Morrison Formation are in the Site area:

- Brushy Basin (youngest) consists of mudstone formed from volcanic ash falls.
- Westwater Canyon consists principally of medium- to coarse-grained, arkosic sandstones interbedded with mudstone units of variable thicknesses.
- Recapture (oldest) consists of grayish-red siltstone and claystone.

At CR-1, the uranium ore was mined primarily from the Westwater Canyon Sandstone. Uranium mineralization within the Westwater Canyon Sandstone occurs as both tabular and roll-type deposits.

After deposition of the Morrison Formation during the Late Jurassic period, no sediments were preserved in the San Juan Basin until the Late Cretaceous rocks including the Dakota Sandstone, Mancos Shale, and Gallup Sandstone. The Dakota Formation consists of fine- to medium-grained, well-sorted sandstone with siltstone and shale interbeds (Hilpert 1963). The Mancos Shale Formation consists primarily of shale, and the upper 200 feet of the Mancos Shale is interbedded with the Lower Gallup Sandstone of the Mesa Verde Group (Canonie Environmental 1988). The Mancos Shale is a regional groundwater confining unit. The Gallup Formation occurs as the Lower Gallup Sandstone and the Upper Gallup Sandstone, and contains the first (uppermost) local bedrock groundwater. The upper Cretaceous Crevasse Canyon Formation is within the Mesa Verde Group and overlies and interfingers with the Gallup Sandstone. It is composed of silty shale, laminated siltstone, sandstone with a clay matrix, coal, shaly siltstone, and silty sandstone. Alluvium overlies the sedimentary bedrock.

Surface geology differs at each of the areas discussed in this AAM. CR-1 surface geology consists of the Crevasse Canyon Formation. The CR-1E and Kerr McGee Ponds surface geologies consist of the Mulatto Tongue of Mancos Shale. However, the Kerr McGee Pond Area is on fluvially deposited Quaternary alluvium that overlies Mulatto Tongue of Mancos Shale. Therefore, each of these sites has a different surface geology, and each of these geologies

has a different background. A map of these units is on Figure 5A. Background for each of these sites has not yet been established.

Hydrology

Groundwater and surface water are two main sources of water in the Church Rock Mining District. The main water-bearing strata in the Church Rock Mining District, from shallowest to deepest, are the alluvial deposits, the Upper Gallup Sandstone, the Lower Gallup Sandstone, Dakota Sandstone, and the Westwater Canyon Sandstone (Figure 5B). Because of the northeast dip of the rock units, each of these strata outcrops along the Pipeline Canyon Arroyo. Aquifer recharge occurs primarily as rainfall infiltrates the shallow subsurface into the alluvial groundwater that moves southwesterly, following the same slope as the ground surface contours. Alluvial groundwater is transmitted to the underlying water-bearing strata at contacts between the strata and alluvium. Groundwater in the water-bearing strata generally flows northeast following the regional dip of the bedrock strata. A potentiometric surface map of the Upper Gallup Sandstone in the Church Rock Mine District shows a northeast flow direction following the regional dip (USEPA 2010a).

The main uranium-bearing rock unit (Morrison Formation) includes the water-bearing Westwater Canyon Sandstone. Depth to groundwater in the Westwater Canyon Sandstone is approximately 1,500 to 1,800 feet bgs. No shaft construction records are available pertaining to the Quivira mine; however, such records are available regarding the nearby NECR site. According to the drilling log for one nearby NECR mine shaft constructed in 1968 and 1969, the first encounter with groundwater occurred at approximately 400 feet bgs in the lower portion of the Upper Gallup Sandstone (MWH 2003). Inflow of water from this formation amounted to 30 to 50 gallons per minute (gpm). The mine shaft drilling logs indicate no encounter with groundwater again until the Dakota Sandstone at the base of the Mancos Shale. Groundwater inflows from the Dakota Sandstone were 800 gpm, and inflows from the Westwater Canyon Sandstone were 1,500 to 2,000 gpm (MWH 2003).

The local communities rely on municipal water provided by the Navajo Nation with only limited groundwater use as stock water. However, a large quantity of mine water was extracted from the Westwater Canyon Sandstone to allow access to ore during mining operations at the NECR and Quivira mines. This process introduced oxygen and temporarily changed the aquifer conditions around the ore rock from anaerobic to aerobic, which can oxidize and mobilize uranium. After mining operations ceased, groundwater around the ore returned to the original anaerobic oxidation state. In addition, disposal of waste rock occurred in mine shafts and stopes during mine closure. Extracted groundwater was discharged via a series of ponds to surface water in Pipeline Canyon Arroyo. The surface water, in turn, recharged the groundwater in alluvium and the Upper and Lower Gallup Formations. The U.S. Geological Survey estimates that over the period of operations of the NECR and Quivira mines, a total of approximately 600 tons of uranium was released into the Pipeline Canyon Arroyo from the mine water discharges alone (Engineering/Remediation Resources Group, Inc. [EERG] 2011). Estimates for aquifer recharge from mine water discharged to the Pipeline Canyon Arroyo were 4,000 cubic feet per day to the alluvium and 32,000 cubic feet per day to the Upper and Lower Gallup Sandstone aquifers (Raymond and Conrad 1982). Discharge of mine water containing oxidized metals affected the quality of water in the local aquifer used for stock watering.

While the non-time-critical removal action focuses on solids, impacts on groundwater have been identified at the downstream but up dip UNC Mill site. No groundwater samples have been collected at CR-1 and CR-1E. In summary:

- Groundwater with an estimated 600 tons of uranium was extracted from the Westwater Canyon Sandstone and discharged to the Pipeline Canyon Arroyo during mining operations at the NECR and Quivira mines. Discharge would have contributed to aquifer recharge in the alluvium, Upper Gallop Sandstone, and Lower Gallup Sandstone (Figure 5B).
- UNC Mill operated unlined tailings disposal cells adjacent to the Pipeline Canyon Arroyo where an estimated 820 million gallons of acidic mine water and sludge was discharged and allowed to evaporate or seep into groundwater (EERG 2011).
- Previous groundwater investigations at UNC Mill found the alluvial sediments in the Pipeline Canyon Arroyo impacted by historical tailings seepage, with detections in historical alluvium groundwater of Ra-226 and radium-228 (Ra-228) at concentrations up to 5.78 picocuries per liter (pCi/L) (EERG 2011).
- Upper Gallup Sandstone groundwater investigations associated with the UNC Mill included sampling for uranium, Ra-226, and Ra-228, with results indicating concentrations of these chemicals in the groundwater at less than federal safe drinking water levels (EERG 2011).
- Immediately following cessation of mining, water quality at the Westwater Canyon Sandstone Aquifer decreased, with elevated uranium concentrations occurring in the UNC Mill well. Since then, the initial post-mining concentrations detected in samples have declined to below federal levels.

Most precipitation occurs from July to October as monsoon thunderstorms. The annual evaporation rate is nearly five times the precipitation rate; consequently, most streams in the area are ephemeral or have flowing water only during storms or rapid snow-melt (USEPA 2007c). The dry conditions and high-intensity rains cause quick saturation of the surface soils, preventing precipitation from penetrating deeper. As a result, intense rainfall drives surface flow into canyon washes, generating short-term and fast-moving streams. These streams produce arroyos that cut through the sedimentary bedrock in the canyons, and erode sediments that are transported downstream to be deposited as alluvium. The alluvium in the canyons and on valley floors consists of fine-grained sand with interbedded silty clay layers. The alluvium directly overlies sedimentary bedrock and aids in transfer of surface water through the shallow groundwater zone in the alluvium to the deeper sedimentary bedrock aquifers (Figure 5B).

A series of arroyos exist throughout the Site. CR-1 is physically separated from the NECR mine site and the residences on Red Water Pond Road to the south by Unnamed Arroyo #2 that runs along the southern boundary of CR-1 (Figure 2). Unnamed Arroyo #2 drains approximately 3,100 acres west and north of CR-1 that includes CR-2 on the mesa above the Site. The width of Unnamed Arroyo #2 typically ranges from 15 to 35 feet with sidewalls 10 to 15 feet high. Abutting the southern side of CR-1, the arroyo drains from west to east and flattens out to a flood plain near its junction with the Pipeline Canyon Arroyo, south of CR-1.

The Pipeline Canyon Arroyo is immediately southeast of CR-1E (Figure 3). The width of the Pipeline Canyon Arroyo typically ranges from 15 to 25 feet with sidewalls 10 to 25 feet high. This arroyo drains from northeast to southwest and flattens out to a flood plain near its junction with Unnamed Arroyo #2, south of CR-1. When surface water runoff occurs, the flow direction is from northwest to southeast along unnamed arroyos and into the Pipeline Canyon Arroyo.

While uranium mining in the area began in the 1950s, National Pollutant Discharge Elimination Systems (NPDES) permits were not obtained until 1973 for NECR mine and until 1974 for Quivira mine. Prior to acquisition of these NPDES permits, groundwater extracted from the Westwater Canyon Sandstone was discharged directly into unnamed arroyos that merged into the Pipeline Canyon Arroyo. The permits set the maximum uranium concentration at 2 milligrams per liter and dissolved Ra-226 at 30 pCi/L (subsequently lowered in 1977 to 3.3 pCi/L). Both NECR and Quivira mines used settling ponds followed by ion-exchange to meet the NPDES permit requirements. Concentrations of uranium and Ra-226 in discharges from both mines frequently exceeded the permit limits during the mine discharge permit period (EERG 2011).

Surface water discharge in the unnamed and Pipeline Canyon arroyos has been highly ephemeral since mine operations ceased and discharge of extracted groundwater terminated. As a result, no surface water samples have been collected.

2.1.5 Land Use and Populations

The Site is in a sparsely vegetated area of shrubs, grasses, and forbs mixed with Pinyon-juniper forests. At some places, the underbrush is predominately sage and snakeweed, while at others, heavily grazed areas of bare ground are prevalent. Current surrounding land use includes agricultural grazing (for livestock such as sheep, cattle, and horses). Navajo families may collect pinyon nuts, herbs, and plants from the surrounding area for food, medicinal, and ceremonial purposes (USEPA 2009a).

Diné Natural Law (1 Navajo Nation code Sections 201-206) declares and teaches the following:

“These natural laws declare and teach that:

- The four sacred elements of life, air, light/fire, water, and earth/pollen in all their forms must be respected, honored, and protected, for they sustain life; and
- The six sacred mountains, Sisnaajini, Tsoodzil, Dook’o’oosliid, Dibe Nitsaa, Dzil Na’oodihi, Dzil Th’ool’i’i, and all the attendant mountains must be respected, honored, and protected, for they, as leaders, are the foundation of the Navajo Nation; and
- All creation, from Mother Earth and Father Sky to the animals, those who live in water, those who fly, and plant life have their own laws and have rights and freedoms to exist; and
- The Diné have the sacred obligation and duty to respect, preserve, and protect all that was provided, for we were designated as the steward for these relatives through our use of the sacred gifts of language and thinking; and

- Mother Earth and Father Sky is part of us as the Diné, and the Diné is part of Mother Earth and Father Sky; the Diné must treat this sacred bond with love and respect without exerting dominance for we do not own our mother or father; and
- The rights and freedoms of the people to the use of the sacred elements of life as mentioned above and to the use of land, natural resources, sacred sites, and other living beings must be accomplished through the proper protocol of respect and offering, and these practices must be protected and preserved, for they are the foundation of our spiritual ceremonies and the Diné lifeway; and
- It is the duty and responsibility of the Diné to protect and preserve the beauty of the natural world for future generations."

According to information conveyed in the 2006 Red Water Pond Road and Pipeline Canyon Road Residents' Resolution, more than 50 Navajo families live in the Red Water Pond Road area of the Coyote Canyon Chapter and the Pipeline Canyon Road area of the Standing Rock Chapter. Figure 6 shows approximate locations of the Red Water Pond Road Community area and the Pipeline Canyon Road Community area as described in a 2012 History through Pictures (Red Water Pond Road Community Association and Southwest Research and Information Center 2012). The nearest residences are approximately 700 feet south of CR-1 and 300 feet north of CR-1E. No public or commercial buildings are within 0.5 mile of the Site. The nearest urban populations are concentrated in Gallup and Church Rock. Gallup is approximately 20 miles from the Site, and had an estimated population of approximately 21,899 in April of 2020 (U.S. Census Bureau [USCB] 2021). Church Rock is approximately 12 miles from the Site, and has a population of approximately 1,100 (USCB 2015b).

Additionally, a water line easement runs through Unnamed Arroyo #2 and CR-1, and El Paso Natural Gas has an easement that runs through CR-1E. El Paso Natural Gas has an approximately 35-foot-wide easement for pipelines where it is adjacent to Pipeline Canyon Road.

2.1.6 Sensitive Ecosystems

No evaluations of ecological resources specific to CR-1, CR-1E, or the Kerr McGee Ponds have occurred. However, baseline biological monitoring for the Environmental Impact Statement (EIS) for the nearby NECR mine identified six vegetative communities in the area: bottomland, grassland, pinon-juniper, reclaimed areas, rock, and shrubland. The EIS also listed 13 federal, state, and Navajo-listed animal species known to inhabit the area, all but two of which were birds. The EIS identified three plant species of concern that are known to or could inhabit the area, including Naturita milk-vetch, Sivinski's fleabane, and Zuni fleabane. No aquatic environments have been documented at the Site (NRC 2020).

2.1.7 Meteorology and Climate

Climate at the Site is semi-arid with a high annual net pan evaporation rate of 54 inches per year. The nearby City of Gallup receives an average annual rainfall of 11 inches (USEPA 2009a). Wind during 11 months of the year typically originates from the southwest, and in the month of August, originates predominantly from the south. Winter and summer average temperatures are

29 and 68 degrees Fahrenheit, respectively (USEPA 2009a). Extreme heat in the summer (100 degrees Fahrenheit) and cold in the winter (-34 degrees Fahrenheit) can occur.

2.2 PREVIOUS RECLAMATION AND REMOVAL ACTIONS

Multiple previous removal activities have occurred on or adjacent to the Site. Previous removal activities are summarized in the subsections below.

Initial Mine Reclamation

The Quivira Mining Company submitted an Abandonment and Reclamation Plan to the U.S. Department of the Interior Bureau of Land Management (BLM) in January 1987. Records indicate that the mine had been placed in standby mode on January 31, 1985. The Abandonment and Reclamation Plan was reviewed by BLM, Navajo Tribal Government, and BIA as part of the Department of Interior's trust responsibilities, and was approved by BLM. BLM issued a Finding of No Significant Impact and a final Record of Decision on September 5, 1990, that allowed reclamation of CR-1 and CR-1E in accordance with the stipulated conditions (SENES 2010).

The reclamation plan specified removals of mine dewatering pumps; mine equipment including hoists, compressors, headframes, and generators; buildings; and foundations. Sediments from the mine water ponds were to be excavated and placed in shafts and ventilation raises. Pond sediments and waste rock were to be deposited in these underground openings. Grizzlies (steel barricades) were to be placed over all shaft openings, monitored for 1 year for subsidence, and backfilled as needed. These mining openings were then to be capped with a 4-foot-thick concrete caps. Final land reclamation including reseeding to the native landscape was to occur. Mine waste piles and all disturbed areas were to be covered with a minimum of 1 foot of topsoil and reseeded with a seed mixture recommended by BIA for the Church Rock area. Based on topography and lithology, some fill material may have been excavated from CR-2 and transported to CR-1 for use as cap material as part of closure activities. Ventilation borehole foundations supporting the casing walls were to remain in place, but surface ventilation fans, transformers, switches, ductwork, electrical cables, and fences were to be removed from the borehole areas (SENES 2010). No clear record of execution of this work is available, but current conditions indicate this work was completed.

It is unclear what actions, if any, occurred to close and remove the former Kerr McGee Ponds at the UNC Mill site (Figure 1). At a minimum, the ponds appear to have been filled to match the surrounding grade. CR-1E hosted similar structures (that is, ponds and a shaft), but on a much smaller scale. The abandonment and reclamation document specified requirements for CR-1E in the same manner as for CR-1 (SENES 2010).

Time-Critical Removal Action, 2010

In 2010, USEPA issued an action memorandum for a time-critical removal action (TCRA) to address the risks associated with soil contamination at the Site (USEPA 2010b). In fall 2010, RAML completed the following under an Administrative Order on Consent with USEPA:

- Performed cultural resource surveys of the mines

- Repaired fences to keep people and livestock off the Site
- Graded and seeded the western slope of the waste rock pile at CR-1
- Applied a soil tackifier to portions of the mine's access road and Red Water Pond Road near the entrance to CR-1
- Installed sediment control structures in the eastern, southern, and western portions of CR-1
- Applied chip seal paving to Red Water Pond Road from the turnoff at Route 566 up to the bridge
- Began sample collection from the mine areas, the arroyos, and nearby property to delineate the Site for the RSE.

Red Water Pond Road Time-Critical Removal Action, 2012

On August 8, 2012, USEPA issued RAML a Unilateral Administrative Order and Statement of Work for the Red Water Pond Road Removal Action (USEPA 2012b), followed by an Action Memorandum for the TCRA on August 21, 2012 (USEPA 2012c). The removal action took place in fall 2012 with USEPA and the Navajo Nation Environmental Protection Agency (NNEPA) overseeing the work. RAML completed the following work as documented in the Red Water Pond Road Removal Action Report (Conestoga Rovers and Associates Ltd. [CRA] and SENES 2013):

- Excavated and removed soils containing concentrations of Ra-226 exceeding 2.24 pCi/g along Red Water Pond Road and within adjacent areas (to the fence line on either side of the road) from Route 566 to Unnamed Arroyo #2
- Excavated and removed some soils from Red Water Pond Road and adjacent areas between Unnamed Arroyo #2 and the existing cattle guard west of the CR-1 entrance (some excavation and re-grading, but corrective actions at this section did not meet cleanup objectives)
- Placed excavated materials onto the waste rock stockpile at CR-1
- Reconstructed the road and shoulder area between Route 566 and Unnamed Arroyo #2, including some wear surface placement on the Red Water Pond Road between Unnamed Arroyo #2 and the entrance to CR-1
- Revegetated disturbed areas.

During the removal action, RAML excavated and removed approximately 17,374 cy of material that was placed on top of the CR-1 waste rock area. Excavated material was placed in 12-inch-thick compacted lifts on the CR-1 storage area, which were subsequently sloped, covered with 3,570 cy of imported fill material, and revegetated. The relocated material was graded so that the slopes of the waste stockpile area did not exceed 4H:1V (CRA and SENES 2013).

Confirmation sampling results indicated successful remediation of the roadway and shoulders, and Ra-226 concentrations below the action level in soil within and along the road between Route 566 and Unnamed Arroyo #2. The abutments to the Red Water Pond Road Bridge were

not remediated as part of this action because of concerns over compromising the bridge, arroyo stability, and physical safety issues working on and near the bridge (CRA and SENES 2013).

Quivira Vent Shaft Removal Activities, 2017

In summer and fall 2017, USEPA conducted removal operations at five ventilation shafts—excavating approximately 10,300 cy of soil from areas surrounding the vent shafts and placing that soil on top of the CR-1 waste rock pile. Residual contaminants remain immediately adjacent to the concrete vent shaft caps. Based on time and budget constraints, not all contaminated material with Ra-226 concentrations above the stipulated action level of 2.0 pCi/g was excavated from Vent Shafts 2, 3, and 5. However, the remaining residual waste at these locations was within 3 to 10 feet bgs, and was capped with a minimum of 3 feet of clean fill material. Excavation of residual contaminated soil (estimated volume as much as 500 cy) may be necessary at Vent Shafts 2, 3, and 5. This volume is small enough to include in any alternative without affecting the analysis, and therefore is not addressed as a separate cost in this AAM. Additional details are available in the Quivira Tronox Mine Removal Action Report for Quivira Vent Holes 1 through 5, Navajo Nation, McKinley County, New Mexico (Weston 2019b).

Cleanup Activities at the Adjacent Northeast Church Rock Mine

UNC is the responsible party for the NECR mine site. In 2007, USEPA issued two TCRA Action Memorandums to address soil contamination at residences near the NECR site (USEPA 2007a, b). The objective was to remove soil around the structures to achieve a cleanup goal of 2.24 pCi/g for Ra-226. Approximately 6,500 cy of soil was excavated, stockpiled, and taken by UNC to a licensed off-site disposal facility. The areas around the homes were restored with clean backfill (USEPA 2009b, 2011a).

In response to a 2009 TCRA Action Memorandum (USEPA 2009b), approximately 109,800 cy of soil was removed from Step Out Area #1 north of the NECR mine site (Figure 6) between August 2009 and May 2010. Excavated soil was placed in a soil consolidation area within the NECR mine site and covered with a minimum of 6 inches of soil on the top of the pile, and a minimum of 12 inches on the slopes (MWH 2010, USEPA 2011a).

In a 2011 TCRA Action Memorandum (USEPA 2011a), USEPA directed removal of contaminated soil from the Eastern Drainage Area (Figure 6). During fall 2012, UNC and its contractors removed approximately 32,000 cy of impacted soils from the East Drainage Area and an unnamed arroyo immediately downgradient of the NECR mine. Excavated soil was placed in a soil consolidation area within the NECR mine site and covered with 6 inches of soil (MWH 2013).

In a 2011 non-TCRA Action Memorandum (USEPA 2011b), USEPA directed removal of approximately 871,000 cy of waste material from the NECR mine site and placement of this waste at the UNC Mill Facility. UNC has completed the design for this action. However, because the waste will be placed at the mill site, which is under a license from the NRC, NRC is conducting a license amendment review that must be completed and approved prior to the action.

2.3 PREVIOUS SITE INVESTIGATIONS

Because of the significant depth to groundwater, arid climate, and interbedded confining geology in the region, rainfall and surface water infiltration do not directly impact groundwater in the Westwater Canyon member. Moreover, no drinking water wells are completed in the Westwater formation near the Site. Therefore, the scope of this AAM focuses only on the nature and extent of contamination at the Site in surface and near-surface soil.

For this AAM, delineation of soil contamination at the Site has been based on data obtained from recent investigations. This section first describes these investigations in chronological order, and then identifies COCs and discusses the nature and extent of contamination at the Site based on results of these investigations. Reviews of following documents aided development of this section:

- Quivira Mines Expanded Site Screening Report (Weston 2010)
- Final RSE Report regarding CR-1 and CR-1E (SENES 2011)
- Red Water Pond Road Removal Action Report (CRA and SENES 2013)
- Quivira Mine Screening-Level Investigation Report (Ecology and Environment, Inc. [E&E] 2012)
- Draft Removal Assessment Report for Quivira Mine Church Rock No. 2 Mine Site, Navajo Nation, McKinley County, New Mexico (Weston 2015)
- Removal Assessment Report for Quivira Mine Site Features Including Quivira Vent Holes 1 through 4, Navajo Nation, McKinley County, New Mexico (Weston 2016)
- Quivira Tronox Mine Former Dewatering Ponds Removal Assessment Report, Navajo Nation, New Mexico (Weston 2019a).

Initial Gamma Screening Investigations, 2008 and 2009

Weston (2010) screened the Northeast Church Rock – Quivira area for gamma radiation during two separate events. In October 2008, Weston, as a USEPA contractor, screened the surface of portions of the CR-1 and CR-1E areas. In October 2009, Weston performed surface and subsurface screening of the arroyos both upstream and downstream of the Site; of portions of Red Water Pond Road, including the bridge area; and of a nearby pond and cornfield belonging to a local resident. This investigation found impacts at the mine sites and the Red Water Pond Road, but not at the cornfield, pond, or arroyos (Weston 2010).

Soil Sampling, Static and Scan Surveys for the RSE, 2010 and 2011

In 2009, USEPA and RAML both signed an Administrative Order on Consent according to which RAML agreed to perform erosion controls on the waste rock piles and investigate the extent of contamination at the Site (USEPA 2009c). RAML sampled the mine areas during fall 2010 and spring 2011, and published the results in the RSE report regarding CR-1 and CR-1E in September 2011 (SENES 2011). Surface and subsurface soil sampling occurred at CR-1, CR-1E, Unnamed Arroyo #2, Pipeline Canyon Arroyo, Red Water Pond Road, and Pipeline Canyon Road.

Results conveyed in the 2011 RSE report (SENES 2011) were used to identify the nature and extent of Ra-226 contamination at the Quivira mines (shown on Figures 7 through 13). Higher gamma activity readings and Ra-226 soil sampling results were found at CR-1 across the waste rock pile area; on the western portions of both the sediment pond and industrial areas; at areas on and adjacent to the Red Water Pond Road Bridge; and in step-out areas northeast of the industrial area, east of the industrial and waste rock areas, and north of Unnamed Arroyo #2. Higher gamma activity readings and Ra-226 soil sampling results were detected at CR-1E across the waste rock pile area, within the sediment pond area, against the bluff in the northern industrial area, and in the step-out area east of the sediment pond and northern industrial areas. Soil sampling results for Ra-226 in the waste rock and industrial areas of CR-1 are shown on Figure 7, and soil sampling results from the former pond areas at CR-1 appear on Figure 8. Soil sampling results from CR-1E are shown on Figure 9.

Borings completed within the waste rock stockpile at CR-1 encountered waste rock as deep as 56 feet below the existing cover. This depth corresponds to the height of the waste rock pile above the pre-mining ground surface. The northern end of the waste rock stockpile extends up onto an outcropping that forms a cliff behind the mine. Bedrock may be encountered at depths as shallow as 1 to 1.5 feet below the cover in that northern portion of the waste rock pile. As the CR-1 waste rock stockpile extends to the south, it becomes progressively deeper, as indicated by four deep borings (Figure 10) from north to south that encountered native sand at 15.5 feet (C1LW-300), 31 feet (C1LW-301), 45.5 feet (C1LW-302), and 56 feet (C1LW-303).

In the CR-1 former industrial area, locations where Ra-226 concentrations exceeded background were primarily in the central and western regions, and averaged from 9 inches to 3 feet in depth, respectively (Figure 10). Waste rock was not encountered outside the CR-1 leased area, and elevated concentrations of Ra-226 generally were not detected in samples collected deeper than 1 foot bgs within the step-out area.

The logs for borings advanced in the former pond area noted two boring locations (C1LP-402 and C1LP-404; Figure 10) where fill material was deeper than 15 feet below the current ground surface. Soil samples from all nine ponds contained Ra-226 at concentrations above background somewhere within the former footprint of the pond. Shallow surface samples collected in the former pond area, but outside of the pond footprints, generally did not contain Ra-226 levels above background. The exception to this was near the southern lease area boundary between Ponds 1, 2, and 3 (near CL1P-020, CL1P-026, and CL1P-031; Figure 8).

Borings completed within the waste rock stockpile at CR-1E encountered waste rock as deep as 20 feet below the existing ground surface. Borings drilled at the former industrial area at CR-1E logged fill to depth of 6 feet. Soil samples collected from the northeast industrial area generally contained Ra-226 concentrations above background concentrations to depth of 1.3 feet, except along the rock outcropping at CELI-502, where elevated activity concentrations in samples extended to a depth of 6 feet bgs. At the southwest industrial area, approximately 6 inches of soil near the southernmost tip of the area contained Ra-226 concentrations above background. No waste rock was encountered outside the CR-1E lease area. Elevated concentrations of Ra-226 in the step-out area were not detected deeper than 18 inches below the current ground surface, except in one boring (CESS-069; Figure 9) where concentrations were elevated at depth of 36 inches.

During the course of the soil sampling for the radiological program, petroleum hydrocarbon odors were reported at CR-1 in boring C1LP-401, within the footprint of former Pond 1A (Figure 10). A soil sample was collected within 9 to 10.5 feet bgs at this borehole location and analyzed for gasoline-range and diesel-range total petroleum hydrocarbons (TPH). The sample yielded 1,300 mg/kg of diesel-range TPH. This sample is considered an anomaly because the duplicate sample result was 3.6 mg/kg. Sampling results from two other borings, C1LI-500 and C1LI-501 (both within the former industrial area), and their duplicate samples were less than 10 mg/kg for diesel-range TPH. At CR-1E, diesel-range TPH results from two samples and two duplicates (borings C1EI-502 and C1EI-503 in the former industrial area) ranged between 7.4 and 14 mg/kg. These data are summarized in the RSE report for CR-1 and CR-1E (SENES 2011).

Supplemental Soil Sampling, Static and Scan Surveys, 2011

During November 2011, USEPA's Superfund Technical Assessment and Response Team performed static and scan gamma activity surveys and collected soil samples from two former cornfields, a former irrigation storage pond that stored water pumped from the mine, and portions of Unnamed Arroyo #2 upstream from the CR-1 mine. The western cornfield was the same as the one evaluated during the 2009 investigation.

The measured gamma radiation activity at the cornfields, pond, and arroyo were below levels that correlate to the screening level of 2.24 pCi/g for Ra-226. Concentrations of Ra-226 in soil samples analyzed at a laboratory were all less than 2.24 pCi/g. The 2.24 pCi/g screening level is the cleanup goal selected for the adjacent NECR mine. Results of this assessment work are summarized in the Quivira Mine Screening-Level Investigation Report (E&E 2012). This investigation did not find mine-related contamination at the cornfield, pond, or arroyos.

Quivira Tronox Mine Vent Hole Assessment Work, 2011–2017

Between 2011 and 2017, USEPA assessed five vent holes (VH-1 through VH-5) associated with the Quivira Tronox Mines (Figure 1). All five vent holes had elevated gamma activity in surface soils, and Ra-226 was detected in surface and shallow subsurface soil samples collected at each location at concentrations greater than the site-specific 2.0 pCi/g action level for Ra-226. Based on the relatively uniform grain size, color, volume, and distribution, most of the vent hole wastes are most likely drilling muds that were used to lubricate the drill string and remove cuttings during vent hole installation operations. Removal actions occurred at the vent holes in 2017 (Weston 2019b).

Data Gap Collection of Additional Soil Boring Data, 2015

In July 2015, Weston installed additional soil borings and collected additional soil samples to better delineate the lateral and vertical extents of contamination associated with CR-1 and CR-1E. Eight borings were installed at CR-1, and six borings were installed at CR-1E. The data were used, together with data collected previously by SENES, to estimate the total volume of waste rock at each site. Locations of the 2015 borings appear on Figures 10 and 11.

Quivira Tronox Mine Kerr McGee Pond Assessment Work, 2017

In early 2017, USEPA became aware that Kerr-McGee had operated a sediment pond and an ore storage area on land leased from the State of New Mexico approximately 2,000 feet south of CR-1E. In addition, office space and a training facility had been located nearby. Reportedly, the various work areas were closed when the state transferred the land to UNC. Preliminary assessment work during summer 2017 indicated presence of elevated gamma activity in surface soils. Action levels for Ra-226 are expected to differ at the former UNC Mill site because it will be regulated under the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA). Under UMTRCA, the cleanup action level for surface soil is expected to be 5.0 pCi/g, and anticipated to be 15 pCi/g for soils deeper than 1 foot bgs. Detected concentrations of Ra-226 exceeded the stipulated action level for the UNC Mill site of 5.0 pCi/g at approximately 10 of the 23 surface sample locations. However, none of the shallow subsurface soil samples collected between 18 and 36 inches bgs yielded an Ra-226 concentration above 15 pCi/g. No deep soil borings were advanced.

The surface detections may be caused by impacts from mill tailings that were wind-blown or water borne into the area. The former tailings storage area for the mill is south and generally upwind from the former Kerr McGee ponds. Mass concentrations of uranium in soil samples collected from the area suggest that Ra-226 and uranium are not in secular equilibrium, a possible indication that the material is more similar to tailings than to ore. Because of the uncertainty of the source and lack of deep soil borings, the Kerr-McGee ponds are considered a data gap. Additional assessment work is currently (as of 2021) recommended in this area prior to design of a final action.

2.4 SOURCE, NATURE, AND EXTENT OF CONTAMINATION

Contaminants of potential concern (COPCs) are analytes that exceeded both background concentrations and regional screening levels (RSLs). The previously considered COPCs for the Quivira mines were Ra-226, Ra-228, arsenic, selenium, uranium, and vanadium. New COPCs may be identified after acquisition of comprehensive background data, which is planned when travel restrictions are lifted.

2.4.1 COPCs and Background Units

The CR-1 mine is within approximately 1 mile of the UNC NECR mine and was initially thought to be in the same geological setting. Thus, background levels developed for the NECR mine (MWH 2006) were originally also applied to the Quivira mines. However, after analysis, the data did not appear to fit the CR-1 site geology. No background data specific to the Quivira sites have been obtained. Based on the differing surface geologies at CR-1, CR-1E, and the Kerr McGee Ponds, each of the three areas will require separate background sampling and evaluation to establish background concentrations. Background data pertaining to all these sites have been identified as a data gap, but field investigation efforts have not been able to move forward because of COVID-19 travel restrictions.

2.4.2 Source and Nature of Contamination

The areas of concern for soil contamination include CR-1 and CR-1E, as well as specific step-out areas indicated by elevated Ra-226 soil sampling results or scan and static survey results. Figures 10 and 11 show the areas of contamination at CR-1 and CR-1E, respectively. Table 1 summarizes Ra-226 sampling data, providing the number of sample results, as well as minimum and maximum values at various depths within each of the areas.

Extents of impacts on the arroyos are a data gap because sampling results indicate presence of limited contamination, with highly variable concentrations laterally and at depth (Figure 7). The average concentration of Ra-226 in Unnamed Arroyo #2 was 1.40 pCi/g based on results from 96 samples collected at 39 locations, but localized areas hosted concentrations as high as 26.9 pCi/g. The average concentration in the Pipeline Canyon Arroyo was 1.42 pCi/g based on results from 35 samples collected at 15 locations. Data from Unnamed Arroyo #2 and Pipeline Canyon Arroyo are conveyed in the 2011 RSE report regarding CR-1 and CR-1E (SENES 2011). These averages were below the RSE screening level of 2.24 pCi/g and the current site-specific action level of 2.0 PCi/g for Ra-226. Soils in the arroyo erode with each storm event. The source of the high concentrations is a data gap. Whether contamination in the arroyos derives from known site sources, from a source that will not be addressed by the removal action, or from soil with elevated concentrations sourced elsewhere and deposited at the site during storms should be identified.

Waste Characteristics

The RSE included collection of two composite samples of waste rock from CR-1 for analysis for metals leachability via both the toxicity characteristic leaching procedure (TCLP) and synthetic precipitation leaching procedure (SPLP). The RSE also included analyses of a composite sample of waste rock from CR-1E for metals leachability via both TCLP and SPLP. All TCLP results were not detected or below regulatory criteria, indicating that the waste would not be classified as a Resource Conservation and Recovery Act (RCRA) hazardous waste if sent for disposal off site (SENES 2011). Such data pertaining to the Kerr McGee Ponds area are not available, and thus waste characteristics at the Kerr McGee Ponds is considered a data gap.

Geotechnical Characteristics

No geotechnical data have been obtained pertaining to the Site including CR-1, CR-1E, and the Kerr McGee Ponds areas.

2.4.3 Extent

Gamma Radiation in Surface and Subsurface Soils

Gamma surveys have occurred at CR-1, CR-1E, and the Kerr McGee Ponds areas. Each data set is insufficient for determining the nature and extent of contamination and developing a risk assessment for various reasons. Below are the summary of each evaluation and identifications of the data gaps necessary to fill in order to fully evaluate the sites. Field work scheduled to obtain the necessary data to address these gaps has been indefinitely delayed because of COVID-19 travel restrictions.

The RAML RSE delineated extents of gamma radiation in surface and subsurface soils at CR-1 and CR-1E. Both surface and subsurface soils are impacted (SENES 2011). The degree to which they are impacted will be evaluated by the upcoming background study. The current gamma survey boundaries end at the western property boundaries even though the static and transect data show potentially elevated gamma radiation up to the CR-1 and CR-1E boundaries. A background study of the CR-1 area has not been completed to evaluate background in the surrounding soils and geology. However, without background data, whether gamma radiation in these areas is elevated cannot be established. Background information and further survey delineation is needed to verify the western and northern extents of contamination. Estimated volumes of waste based on available data and used to estimate costs in this AAM are shown in Table 2.

At the Kerr McGee Ponds, scanning has revealed impacts from gamma radiation on surface soil. However, no subsurface data are available to evaluate the subsurface extent of the impacts, and this is considered a data gap. This AAM assumes contamination to depth of 8 feet over an area of 9.9 acres (based on gamma scanning) for an estimated contaminated soil volume of approximately 127,500 cy. This estimate will be revised after completion of additional investigations at the Site.

Metals and Radionuclides in Surface Soils

Non-radiological soil sampling occurred at four locations—two at CR-1 (C1LI-500 and C1LI-501) and two at CR-1E (C1EI-502 and C1E1-503); all four were borings in former industrial areas. Samples were analyzed for metals (arsenic, molybdenum, selenium, and vanadium), and also underwent TCLP and SPLP analyses for waste characterization. Arsenic was the only metal detected at concentration above a USEPA industrial screening standard, but its concentrations were below New Mexico Environmental Department (NMED) screening level standards. The two samples (one waste rock composite and one boring composite) submitted for both TCLP and SPLP metals analyses were also below USEPA toxicity characterization limits (SENES 2011).

Delineation of Technologically Enhanced Naturally Occurring Radioactive Material (TENORM)

CR-1

TENORM at CR-1 includes all waste rock, removal action soil, soil disturbed around the portals, and former pond areas (Figure 12). The lines of evidence used to develop the boundary include site use history, results from gamma surveying, and site observations. After completion of background studies and further delineation at CR-1, this delineation may change.

CR-1E

TENORM at CR-1E includes all waste rock, soil disturbed around the portals, and former pond areas (Figure 13). The lines of evidence used to develop the boundary include site use history, results of gamma surveying, and site observations. After completion of background studies and further delineation at CR-1E, this delineation may change.

Kerr McGee Ponds

TENORM at CR-1E includes all waste rock, soil disturbed around the portals, and former pond areas. The delineation of this appears on Figure 4. The lines of evidence used to develop the boundary include site use history and results of surface gamma surveying. After completions of background, subsurface, and further surface investigations, and further delineation of the Kerr McGee Ponds, this delineation may change.

2.5 RISK ASSESSMENT

The CR-1 mine is within approximately 1 mile of the UNC NECR mine and was initially thought to be in the same geological setting. Thus, background levels developed for the NECR mine (MWH 2006) were also originally applied to the Quivira mines. However, after analysis, the background data did not appear to fit the CR-1 site. No background data specific to the Quivira sites have been obtained. Based on the differing surface geologies at CR-1, CR-1E, and the Kerr McGee Ponds, each of the three areas will require separate background sampling to establish background concentrations. Background data pertaining to each site have been identified as a data gap, and will be addressed during a field investigation this spring. At that time, background datasets will be developed for each geology, a risk assessment will be conducted, and site-specific removal action goals will be developed. To facilitate preparation of this AAM, the extent of cleanup has been defined based on observed TENORM and extent of detected elevated gamma radiation at and beyond the boundary of each of CR-1, CR-1E, and the Kerr McGee Ponds.

3.0 IDENTIFICATION OF REMOVAL ACTION OBJECTIVES

3.1 REMOVAL ACTION OBJECTIVES

The first step in developing removal action alternatives is to establish removal action objectives (RAO). Under the Comprehensive Environmental Response, Compensation, and Recovery Act (CERCLA), removal action alternatives may not require remediation of naturally occurring radioactive material (NORM) or soil to concentrations below background levels. Taking current and potential future land use and Navajo cultural considerations into account, the RAOs are to:

- Prevent exposure to soil containing contaminant concentrations that would pose an unacceptable risk to human health with residential use and traditional Navajo lifeways outside of any potential capped area.
- Prevent exposure to soil containing contaminant concentrations that would pose an unacceptable risk to human health with traditional Navajo lifeways on any potential capped area. This may include exposures during activities such as livestock grazing, hunting, and plant gathering and use.
- Prevent exposure to soil containing contaminant concentrations that would pose an unacceptable risk to plants, animals, and other ecological receptors.
- Prevent migration of contaminants to surface water or groundwater that pose an unacceptable risk to human health.
- Prevent off-site migration of contaminants at levels above background concentrations and at concentrations that could pose a risk to human health or the environment.

A technical memorandum on technology screening and alternative development for Navajo Nation abandoned uranium mines (AUMs) (Technology Technical Memorandum, Tetra Tech 2021a) describes the general response actions that will achieve the RAOs listed above. No risk assessment has been conducted to identify COCs or to establish removal action objectives .

The remainder of this section describes statutory limits on removal actions, and the removal scope and schedule. Section 4.1 summarizes the technology screening and alternative development process that appears in the Technology Technical Memorandum (Tetra Tech 2021a). Section 4.2 describes the retained removal action alternatives for the Quivira Tronox Mine Sites, and Section 4.3 presents a detailed analysis of the removal action alternatives with respect to effectiveness, implementability, and cost criteria established in the National Oil and Hazardous Substances Pollution Contingency Plan (NCP). Section 5.0 presents a comparative analysis of the removal action alternatives.

3.2 STATUTORY LIMITS ON REMOVAL ACTIONS

Pursuant to CERCLA Section (§) 104(c)(1), the normal statutory limits for CERCLA removal actions of $2 million and 12 months do not apply because the selected action will be funded by a responsible party and not by Superfund.

3.3 REMOVAL SCOPE

The scope of the removal action will be to address all solid media contamination at the Site, under the assumption that this will be the final action regarding solid media at the Site. The removal action will also protect against potential future impacts on groundwater and surface water. Post-removal action site controls will be included under an alternative that does not specify complete removal of contaminants to an off-site location.

3.4 REMOVAL SCHEDULE

Preparation of this draft AAM does not include a preferred removal action alternative in order to provide opportunity for public input on the processes for development and evaluation of removal action alternatives. Following public input, USEPA will prepare a final AAM, including a recommended removal action alternative for public comment.

The NCP requires a minimum public comment period of 30 days following release of the proposed final AAM by USEPA. USEPA will respond to significant comments received during the public comment period and publish an action memorandum following the response to comments. USEPA will provide public notification of the removal action schedule upon issuance of the action memorandum.

During implementation of the selected removal action alternative(s), several factors may affect the removal action schedule, including removal action planning and design, cultural and biological clearances and mitigation, seasonal weather-related restrictions, and access for construction equipment. Depending on the removal action alternative selected in the final AAM, design and implementation of the construction activities will likely require between 4 and 6 months. Annual inspections and maintenance of graded and revegetated site surfaces will be necessary at mine sites for at least the first 10 years after restoration. Annual inspections and maintenance of a repository cap, if selected, will occur as specified in a site-specific, long-term surveillance plan (prepared in accordance with 10 *Code of Federal Regulations* [CFR] § 40.28) with inspection frequencies adjusted based on cover or cap stability and inspection findings.

4.0 IDENTIFICATION AND ANALYSIS OF REMOVAL ACTION ALTERNATIVES

Section 4.1 summarizes the process of screening potential technologies, and identifies the removal action alternatives that may be effective and implementable at the Site. Section 4.2 describes in detail the retained removal action alternatives. Section 4.3 provides a detailed analysis of the removal action alternatives based on NCP effectiveness, implementability, and cost criteria.

4.1 DEVELOPMENT AND SCREENING OF ALTERNATIVES

This section identifies general response actions, identifies and screens technologies, develops and describes potential removal action alternatives, and identifies ARARs.

4.1.1 Summary of Technology Identification and Screening

The removal action alternative development process involves identifications of general response actions, technology types, and process options that may satisfy RAOs. General response actions, technologies, and process options considered for all AUMs on the Navajo Nation have been identified, described, and initially screened in the Technology Technical Memorandum (Tetra Tech 2021a). The initial screening eliminates from further consideration infeasible technologies and process options, and retains potentially feasible technologies and process options.

A technology or process option can be eliminated from further consideration if it does not meet the effectiveness threshold criteria (protectiveness and compliance with ARARs) or substantive implementability criteria (technical, administrative, availability, and local acceptance), details of which are conveyed in Section 4.3. In addition, a technology or process option can be eliminated if its cost is substantially higher than other technologies or process options and at least one other technology or process option is retained that offers equal protectiveness.

Technologies or Process Options Screened from Consideration. The following process options identified in the Technology Technical Memorandum were removed from consideration as infeasible during development of this AAM for the Site:

- **Excavation and Disposal at UMTRCA Sites.** Several UMTRCA sites assessed for disposal of Quivira Tronox Mines waste were considered infeasible because those sites were closed, had insufficient capacity to receive the waste, or had groundwater contamination issues that could prohibit disposal under the Off-Site Rule.
- **Excavation and Disposal at Unlicensed Disposal Facilities.** Use of two currently unlicensed locations for new disposal facilities at abandoned coal mines near Grants and Fort Wingate was considered infeasible. Factors included the long time required to license new disposal facilities, whether the coal mines could meet licensing requirements, and contamination issues at both sites that could prohibit disposal under the Off-Site Rule.
- **Excavation and Disposal Back into Mine Adits and Workings**. Although Quivira Tronox Mines development information is limited, some waste is believed to have been slurried into the shaft and nearby tunnels when the Quivira mines closed. Access to the mine shafts is no

longer available. Digging a new shaft to access tunnels would be unsafe and infeasible. Disposal in the former workings also could negatively impact groundwater.

- **Disposal at a Local Municipal Solid Waste Landfill.** No municipal solid waste landfill is present on the Navajo Nation, but several landfills are nearby in Arizona and New Mexico. Local landfills were screened from consideration as disposal options because of the explicit exemption of uranium mine waste from the definition of solid waste in state regulations. Thus, the permits for local landfills do not allow disposal of uranium mine waste.
- **Excavation and Disposal at the UNC Mill Tailings Area.** The UNC Mill Tailings Area was selected as the preferred alternative for disposal of contaminated soil from the NECR mine. However, disposal of waste from the Site at the UNC Mill Tailings Area is considered administratively infeasible for several reasons:
  - The property owner (UNC) is unwilling to accept the waste at this time.
  - The process to design placement of NECR waste at the UNC Mill Tailings Area is underway, completion of which is not expected until later in 2022. The preliminary designs indicate little likelihood that extra capacity to accept waste from the Site will exist after the NECR removal action. Moreover, evaluating the required changes to the remedial design would delay the remedial process for the NECR mine.
  - The UNC Mill Tailings Area is under an NRC license that must be amended by the NRC prior to placement of any waste. NRC estimates that this will take 2-3 years after approval of the design. Adding waste from the Site to that license termination process would result in further delays.
  - The U.S. Department of Energy (DOE) Legacy Management Program assumes land ownership and long-term maintenance responsibility for mill sites after termination of NRC licenses. Adding waste from the Site to the design would necessitate additional delays.
  - Both USEPA and the community are committed to implement (and hopefully overlap) both the Quivira and NECR actions within the smallest possible time frame to minimize impacts on the community. However, transport and placement of waste from both the NECR mine and the Site to the UNC Mill Tailings area concurrently would increase potential for construction and transportation bottlenecks and delays.

  This option was eliminated from this AAM because too many legal, administrative, and implementation hurdles would have to be addressed, and would likely add years to both the Quivira and NECR actions.
- **Excavation and Disposal at the Leased Area for the CR-2 Mine.** The leased area for the CR-2 mine was considered as a disposal site because it is not near any established home sites and could be considered part of the Site under CERCLA, allowing for permit exemptions during work there. However, the needs for installation of a perimeter access road and maximum repository slopes of 3.5H:1V would limit the approximately 10-acre site to a maximum capacity of 384,000 cy. That capacity would be even less considering the likely requirements for hardened drainages and support areas. The current estimated volume of waste from CR-1, CR-1E, and Kerr McGee Ponds is 1,041,000 cy, and thus the

leased area for the CR-2 mine lacks the capacity to accommodate the estimated amount of waste from the Site.

- **Use of Both Upper and Lower Synthetic Liners for Repositories.** On-site disposal was evaluated as a removal alternative. Each on-site disposal alternative involves two cover options: (1) using a store-and-release (also known as evapotranspiration [ET]) cover, and (2) using an upper synthetic liner with a store-and-release cover. Use of both an upper and lower liner has been screened out because this would add significant additional cost without adding protection. A Hydrologic Evaluation of Landfill Performance (HELP) model was used to evaluate the difference in percolation through a cover system with one upper liner and another with both an upper and lower liner. Given the low precipitation and high pan evaporation at the Site, the difference in percolation between the two models was 0.0002 inch. Because precipitation measurement input into the model is only accurate to 0.1 or 0.01 inch, the modeled percolation value is zero. However, the difference in cost between using only an upper liner and upper and lower liners is significant. Preliminary cost estimating indicated that addition of a lower liner would increase on-site disposal costs by approximately $6 to $7 million. Most of that cost would be for double handling the wastes (removing and replacing after liner installation). Because there is little added protection and significant cost, lower liners are not considered for on-site disposal.

Analysis of Whether Treatment to Reduce Toxicity or Volume Is Practicable. CERCLA and the NCP express a preference for treatment of waste that significantly and permanently reduces the volume, toxicity, or mobility of contaminants, where such treatment is practicable. CERCLA § 121(b), 40 CFR § 300.430(a)(1)(iii), and USEPA Guidance on Principal Threat and Low Level Threat Waste (USEPA1991a) describe how to identify wastes that may be appropriate for treatment. Although the action at the Site is a removal action, USEPA has nevertheless fully considered whether the Site contained any principal threat waste, whether that waste could safely be contained by imposition of engineering controls, and whether any treatment options may be practicable for the waste at the Site. As a result of the analysis, USEPA concluded that, while individual samples at the site contained higher levels of contaminants that might be considered principal threat waste, the waste at the Site is extremely variable and heterogeneous. Thus, USEPA designated no areas of waste rock as clearly distinguishable as principal threat waste. In addition, consistent with 1991 guidance, USEPA found that the wastes at the site can be safely and reliably contained using appropriate engineering controls. USEPA reviewed potential treatment options and concluded that no currently available treatment options are practicable as follows:

- **Phytoremediation** is a treatment process that uses plants to absorb radionuclides and other contaminants. This and similar alternative treatment methods were considered but screened out as infeasible for the Site. Much of the contamination at the Site is buried in 40-to-50-foot-deep piles and would not be easily accessible by plant roots. Moreover, since plants used in phytoremediation must be harvested and sent for disposal as a radioactive waste, prevention of human or animal consumption of the plants would be necessary. The waste would have to be spread out over a large area, which would further contaminate additional areas. Phytoremediation has not been shown to reduce Ra-226 concentrations in former mining waste to the extent needed to meet the removal action goals. Because of the limited planting area, limited access, limited depth of root penetration, and harvested material handling requirements, phytoremediation was determined not practicable.

- **Soil washing** is a treatment process that involves washing the contaminated medium (with water) in a heap, vat, or agitated vessel to dissolve water-soluble contaminants. Soil washing requires that contaminants be readily soluble in water and sized sufficiently small so that dissolution can be achieved within a practical retention time. The most common forms of uranium oxides in waste rock at the Site have low solubility in water, rendering soil washing ineffective for removal to below remediation goals. Arsenic solubility depends on the arsenic compounds that are present in the waste rock and can range from highly soluble to insoluble. Highly soluble metals in the wash solution are then precipitated as insoluble compounds and the treated solids are dewatered. The precipitates may form a sludge requiring additional treatment, such as dewatering or stabilization, prior to disposal. Because of the low concentrations of uranium in the waste rock and varying solubilities at different pH ranges of radionuclides and metals of concern, soil washing likely will not meet cleanup goals and is determined not practicable.
- **Acid extraction** is similar to soil washing except an acidic solution instead of water is applied to the waste rock or other contaminated media in a heap, vat, or agitated vessel. Depending on temperature, pressure, and acid concentration, varying quantities of metal constituents would be solubilized. A broader range of contaminants are expected to be acid-soluble at ambient conditions with acid extraction than with soil washing. Dissolved contaminants are subsequently precipitated for additional treatment and disposal. Based on the low concentrations of uranium in the waste rock and varying solubilities of radionuclides and metals of concern at different pH ranges, acid extraction likely will not decrease concentrations of all contaminants below remediation goals. Acid extraction likely will not meet removal action goals established for other similar sites and is determined not to be practicable.
- **Ablation** is a treatment technology that can be applied to sandstone-hosted uranium mineralization, where the uranium minerals form a crust on the sand grains. The ablation process mixes water and waste rock into a slurry that is injected into impact tank modules. The opposing slurry streams impact one another, and collisions between the sandstone particles and fragments within each stream result in disassociation of fine-grained, intergranular, and mineralized material (uranium minerals) from coarser-grained sands. Ablation technology has potential for treating waste rock with low uranium concentrations in some small commercial systems in operation, and pilot-scale studies are planned to test the feasibility of the technology. However, ablation technologies have not proven capable of removing low-concentration uranium from waste similar to the waste rock at CR-1 and CR-1E, and have not demonstrated sufficient throughput to address a large volume of waste rock in a timely manner. Therefore, ablation is determined not practicable.
- **Milling** is a commercial process that removes uranium by a combination of several methods including pulverization and acid extraction. Concentrations of uranium in the waste rock at the Site are low, so any processing would therefore yield only a minimal amount of uranium. Additionally, milling does not remove radium, and the resulting mill waste is neither less toxic nor less mobile than the source material. Thus, milling is determined not practicable for treatment of uranium mine waste. However, milling may be considered as a pretreatment step for recovering uranium before disposal in a tailings disposal facility, and thus is retained as a disposal process option.

If the treatments discussed above or any other treatment methods are shown to be effective and practicable before selection of a remedy, USEPA will amend this analysis and consider such treatments.

4.1.2 Summary of Alternative Development

Excavation and disposal was the only technology identified as implementable and effective for the Site. Removal action alternatives for AUMs on the Navajo Nation were developed as described in the Technology Technical Memorandum (Tetra Tech 2021a). Retained removal action alternatives for the Site are based on site-specific conditions and other local requirements. The removal action alternatives are:

- **Alternative 1: No Action** – No new treatment, containment, or response action would occur at the Site. Operation and maintenance of the existing soil cover and site controls would continue. The No Action alternative has been included as a requirement of the NCP and to provide a basis for comparison of the remaining alternatives. Exposure to COCs by human and ecological receptors would not be reduced.
- **Alternative 2: Consolidate and Cap all Waste at Quivira CR-1** – Contaminated soils from CR-1, CR-1E, and the Kerr McGee Ponds would be consolidated and capped at Quivira CR-1. Two cover options are under this alternative are as follows:
  - Alternative 2A assumes use of a store-and-release cover (ET cover) at CR-1.
  - Alternative 2B assumes use of an upper synthetic liner in addition to a store-and-release cover at CR-1.

  The alternatives are identical except for inclusion of the additional synthetic liner in Alternative 2B. Both capping options would be designed to meet performance criteria in order to achieve specified radon flux attenuation goals.
- **Alternative 3: Consolidate and Cap all Waste Separately at Quivira CR-1 and Quivira CR-1E** – Contaminated soils at Quivira CR-1 and the Kerr McGee Ponds would be consolidated and covered at CR-1 and contaminated soil at Quivira CR-1E would be consolidated and covered at CR-1E. Two cover options are presented under this alternative:
  - Alternative 3A assumes using a store-and-release cover (ET cover) only for the waste.
  - Alternative 3B assumes using an upper synthetic liner in addition to a store-andrelease cover for the waste.

  The alternatives are identical except for the inclusion of the additional synthetic liner under Alternative 3B. Both cover options would be designed to meet specified radon flux attenuation goals.
- **Alternative 4: Reprocess or Dispose of All Mine Waste Off Site at a Licensed/Permitted Facility** – Contaminated soils with concentrations above the action levels would be excavated and either reprocessed and disposed of at White Mesa Mill in Blanding, Utah or disposed of at a RCRA-licensed facility such as the Clean Harbors Deer Trail Landfill in Deer Trail, Colorado.

Retained removal action alternatives are fully described in Section 4.2.2 and will be carried through a detailed analysis in Section 4.3.

4.1.3 Applicable or Relevant and Appropriate Requirements

While CERCLA § 121(d) requires that remedial actions attain standards, requirements, criteria, or limitations that are determined to be ARARs, this section does not apply to removal actions and does not specifically require that removal actions attain ARARs. However, pursuant to the NCP at 40 CFR § 300.415(j), USEPA has promulgated a requirement that removal actions attain federal and state ARARs to the extent practicable considering the exigencies of the situation. The Quivira Tronox Mine is located on Navajo Nation land. Pursuant to the NCP at 40 CFR § 300.5, the term "state" includes American Indian tribes. Therefore, for purposes of evaluating potential ARARs, tribal requirements will be treated the same as state requirements. The identification of ARARs is an iterative process; therefore, ARARs are referred to as potential until the final determination is made by USEPA in the action memorandum.

The NCP at 40 CFR § 300.5 identifies ARARs and other "To Be Considered" (TBC) criteria as follows:

- **Applicable requirements** are defined as "those cleanup standards, standards of control, and other substantive requirements, criteria, or limitations promulgated under federal environmental or state environmental facility siting laws that specifically address a hazardous substance, pollutant, contaminant, remedial action, location or other circumstance found at a CERCLA site."
- **Relevant and appropriate requirements** are defined as "those cleanup standards, standards of control, and other substantive requirements, criteria, or limitation promulgated under federal or state environmental or facility siting laws that, while not 'applicable' address problems or situations sufficiently similar to those encountered at the CERCLA site and that is well suited to the particular site."
- **TBC criteria** consist of advisories, criteria, or guidance that were developed by USEPA, other federal agencies, or states that may be useful in developing CERCLA remedies and include non-promulgated guidance or advisories that are not legally binding and that do not have the status of potential ARARs. TBCs generally fall within three categories: health effects information with a high degree of credibility, technical information on how to perform or evaluate site investigations or response actions, and policy.

Factors to be considered when determining relevance and appropriateness are discussed in the "Technical Memorandum on Applicable or Relevant and Appropriate Requirements for Navajo Nation Abandoned Uranium Mines" (Tetra Tech 2021b).

ARARs apply to on-site actions completed as part of a removal action. The on-site actions evaluated in this AAM will occur exclusively on Navajo Nation land. Therefore, the State of New Mexico lacks regulatory jurisdiction, and State of New Mexico statutory or regulatory requirements are not evaluated as potential ARARs (USEPA 1989a). Compliance with ARARs requires compliance only with the substantive requirements contained within the statute or regulation and, pursuant to CERCLA § 121(e)(1), does not require compliance with procedural requirements, such as permitting or recordkeeping. ARARs do not apply to off-site and off-Navajo

Nation response actions. Instead, off-site and off-Navajo Nation response actions must only comply with independently applicable requirements (not relevant and appropriate) and must comply with both substantive and procedural components of the requirements.

USEPA, as the lead agency, is responsible for identifying potential federal ARARs and evaluating potential tribal ARARs identified by the Navajo Nation. For a tribal requirement to be identified as a potential ARAR, the requirement must be more stringent than the corresponding federal ARARs.

USEPA has divided ARARs into three categories: chemical-specific, location-specific, and action-specific. The three categories are described below:

- **Chemical-Specific ARARs** are usually health- or risk-based numerical values or methodologies that, when applied to site-specific conditions, result in the establishment of numerical values. These values establish the acceptable amount or concentration of a chemical that may be found in, or discharged to, the ambient environment.
- **Location-Specific ARARs** apply to the geographical or physical location of the site. These requirements limit where and how the response action can be implemented.
- **Action-Specific ARARs** include performance, design, or other controls on the specific activities to be performed as part of the response action for a site.

The potential ARARs for this response action are presented and analyzed in Tables 3, 4, and 5 by ARAR category and address any site- and alternative-specific requirements specific to the Quivira Tronox Mines. A full description and analysis of potential ARARs is presented in the ARARs Technical Memorandum (Tetra Tech 2021b).

4.2 DESCRIPTION OF ALTERNATIVES

Retained removal action alternatives for the Quivira Tronox Mines are listed below along with a summary of common site construction and restoration elements applicable to all alternatives. A detailed description of removal action alternatives and associated costs, which focuses on the different waste disposal options, is presented in Section 4.2.2.

4.2.1 Summary of Alternatives and Common Elements

The removal action alternatives for the Quivira Tronox Mine are:

- Alternative 1: No Action
- Alternative 2: Consolidate and Cap all Waste at Quivira CR-1
- Alternative 3: Consolidate and Cap all Waste Separately at Quivira CR-1 and Quivira CR-1E
- Alternative 4: Reprocess and/or Dispose of All Mine Waste Off Site at a Licensed/Permitted Facility

4.2.1.1 Common Elements

To reduce repetitive discussion in the detailed alternative analyses, common removal action elements for Alternatives 2 through 4 are provided below.

Site Preparation.

Laydown areas will be established near the Quivira Tronox Mines. Laydown areas include port-a-potties, wash water, refuse pickup, decontamination station, temporary offices, temporary Wi-Fi and radio, and potentially a construction water well and tank stand. The laydown areas will also include security personnel and temporary fencing and signage for access controls. Laydown areas will remain until completion of the removal action.

A sufficient water supply is not available for construction near the Quivira Tronox Mines. Purchase of water from the Navajo Tribal Utility Authority (NTUA) or construction of a new construction supply well near the CR-1 repository will be needed to provide water for the project. Utility water could be obtained from NTUA or City of Gallup depending upon existing infrastructure and the volume of water available. Well depths will likely range from 500 to 700 feet if utility water is not available. Generators for site power will be used to run the well pump. A water storage tank for the water trucks will also be required. If a well is constructed, it could be left for use by the Navajo community for irrigation or livestock.

Cultural and Biological Exclusion and Timing.

Cultural resource surveys of Quivira CR-1 and CR-1E were conducted in 2010. The results of these surveys would be reviewed and used where possible. If necessary, additional surveys would be performed by a Navajo Nation-approved archeologist, and compliance requirements for cultural resources would be specified by USEPA and concurred on by the Navajo Nation Historic Preservation Department. For the purposes of this AAM and consistent with other CERCLA actions taken in this area, it is assumed that cultural resources can be avoided or protected during site work activities, and that no special status plant or animal species would be identified that would limit site work activities.

Natural resource surveys (for example, biological and botanical) for special status species would verify the current land use for each area, mapped habitat and vegetation cover types, and recorded locations of potential special status species resources. Consultation with Navajo Department of Fish and Wildlife and review of previous surveys would be used where possible, and new surveys would be conducted if necessary. Furthermore, if newly considered areas are identified as part of the selected removal action, these areas would need to be surveyed prior to earthmoving activities. If any natural resources are found, then ARARs will be identified.

The removal actions would involve widening trails for haul roads and an overall larger work area than the previous investigations. Therefore, additional field surveys and reports, for both natural and cultural resources, of the proposed work areas would be required, in consultation with the Navajo Nation. The surveys must conclude that the proposed removal action project area would not affect these resources before design and construction could proceed.

An environmental protection plan would be developed for monitoring protocols during the work activities and include a review and evaluation of potential impacts to historic properties and locations. Natural resource (for example, biological and botanical) inspections would be conducted at the Site and information from these inspections would be included in the environmental protection plan. Environmental protection would include a review and evaluation of potential impacts on government-protected species and critical habitats.

Site Access.

During the response and restoration activities, Site access would be restricted by the existing fence and temporary fencing would be constructed where the existing fence may need to be removed in order to perform work. Security would be maintained during all non-working hours while site work is occurring. The Site Foreman and the Health and Safety Officer would be responsible for personnel while they are on the site. To restrict access, the Site would remain completely fenced throughout the duration of construction activities. Temporary fencing would be used whenever the permanent fence must be removed for construction access. Alternate entrances that may be required for portions of the work would be secured when not in use. If work is occurring at Quivira CR-1, Quivira CR-1E, and Kerr McGee Ponds simultaneously, then security would need to be provided at all sites. USEPA and its authorized representatives, including its contractors, and representatives of NNEPA, would have access to the Site at all times. A Site Access and Security Plan would describe the activities used to monitor and control access to the Site during implementation of the response actions and the period of work performance. Domestic livestock would not be allowed to enter the Site until it is fully restored. Once vegetation is restored and the Site has stabilized, perimeter fencing at the Quivira Mine Site may be removed under some alternatives. Restoration activities may take 5 years or more before adequate vegetation is in place and final stabilization is achieved.

The alternatives being considered require an extensive amount of soil and water hauling over several years. During transport, traffic controls would be necessary. A Traffic Control Plan would be developed and followed throughout operations. Even with precautions, the roads in the vicinity of the Site would require maintenance to protect the roadway and users of the roads. In order to maintain road load limits, scales would be used to weigh trucks that would navigate Navajo Nation roadways. Observing road load limits would help to reduce roadway wear and maintain the local roadways in a safe operating condition. Equipment and materials would be available to restore Red Water Pond Road and Pipeline Road as needed.

Air Monitoring.

A Sampling and Analysis Plan would be prepared that describes methods and procedures for collecting, analyzing, and evaluating air samples within and at the perimeter of work zones and within the community. Air monitoring stations would be positioned and operated to monitor dust and airborne contaminant concentrations during grubbing, excavation, stockpiling, loading of bulk carriers, stockpile management, and site restoration. Air monitoring results and dust suppression measures would be implemented to document that off-site migration of contaminants at unacceptable activity concentrations does not occur, to maintain compliant air quality conditions and a safe working environment, and to protect the health of nearby residents, workers, the general public and the environment. Frequent water spraying would be used during soil moving activities

at all work zones and for dust suppression. Water would be sourced from an off-site source or a permanent well installed near Quivira CR-1.

Dust Control.

Off-road haul routes and site excavation and restoration areas would be wetted so that dust generation is minimized. Frequent water spraying would be used during soil moving activities for dust suppression. Further, rock fields and grating will be used to reduce track out of dirt onto paved surfaces. Other unpaved haul routes on Navajo Tribal Lands would be shaped or otherwise improved so that they are free draining and would not easily erode. In order to maintain the haul routes as laid out, signs and barriers would be provided, as necessary, to contain traffic along the designated route. Water used for dust control and cleaning of paved surfaces will be imported or pumped from a new construction well as described above. Dust control will be used to maintain compliant air quality conditions and a safe working environment and will also protect the health of nearby residents, workers, the general public, and the environment.

Stormwater Control.

Excavated areas would be graded to pre-mining contours when possible and oriented to reduce scouring with low-energy flow rates and patterns. The drainage system would be integrated with the topography and existing drainage patterns to the extent possible. Activities at the Site must be evaluated for potential impacts on federally listed species and critical habitat and for certification to meet the substantive requirements of the NPDES Multi-Sector General Permit. Once the Site has been stabilized, monitoring of construction stormwater runoff would cease and post-response-action site controls would be initiated. The cost estimates include provisions for ongoing cover maintenance, and erosion control and fence inspection and repair.

Excavation Approach.

Waste rock and contaminated soils are the removal areas of concern (Figures 10 and 11). The approximately 1,041,000 cy of waste is easily accessed. Waste excavation methods considered for the Quivira Tronox Mine include standard- to large-size excavators and loaders. Waste rock and contaminated soils will be temporarily stockpiled for load out. Borrow material will first be obtained from on site. Additional borrow material may need to be imported.

Waste Handling and Transfer.

For Alternatives 2 and 3 – Consolidation and Capping, waste will remain on site and will be hauled using a 15-30 cy articulated dump truck. For Alternative 4 - Off-Navajo Nation Disposal, waste will be loaded into covered 25-ton on-highway haul trucks. The haul trucks will proceed to Pipeline Road via a short unpaved road. No transfer station will be required because the Site can be accessed with multiple types of trucks. Dry brushing of all truck bed and wheels will occur before each truck leaves the site.

Cap Design Assessment.

Containment in an on-site repository (Alternatives 2 and 3) would involve the construction of an engineered cap over the consolidated mine waste. Two types of engineered caps were evaluated

through infiltration and radon flux modeling in the Technology Technical Memorandum: a soil ET cap and a soil cap containing an integral high-density polyethylene (HDPE) layer (Tetra Tech 2021a).

A total of 36 inches of cover is required for an ET cap to prevent infiltration of precipitation and snowmelt, control radon gas flux, and reduce gamma activity to background. A cap with an HDPE liner would require less soil cover; however, 24 inches of cover would still be needed to protect the liner from frost heave, burrowing animals, and plant roots.

Both engineered cap types would minimize the vertical migration of precipitation and snowmelt to and contact with underlying mine waste. However, an ET cap would allow for slow dissemination of radon gas while a soil cap with an HDPE liner would tend to trap radon gas, which may find preferential pathways for a release at higher concentrations.

There are nearby sources of soil for cap design along Pipeline Canyon. These include the fluvial deposits in the drainage and above the earthen dam northeast of CR-1E. Investigations into the suitability of these soils as cap materials is planned for when travel restrictions are lifted.

Site Restoration Activities.

USEPA has developed a matrix in the "Navajo Nation Surficial Restoration Approaches Technical Memorandum" (Restoration Technical Memorandum) to identify different features and areas of mine sites requiring restoration and typical restoration approaches for each feature and area (Tetra Tech 2021c). Table 7 identifies the mine features and areas present at the Quivira Tronox Mine along with general restoration approaches. Further details regarding each feature and area requiring restoration are described below:

- *Access Roads*. All access roads needed for the project already exist for CR-1, CR-1E, and the Kerr McGee Ponds. Minor improvements may be made to the existing roads. Any construction-related damage to the existing dirt road will be repaired and may involve grading and repair of drainage ditches.
- *Waste Excavation Areas.* Excavated areas will be backfilled with soil from a local borrow area and contour graded to match adjacent topography, covered with an erosion control blanket, and seeded using local grasses and forbs. Temporary 4-strand barbed wire fencing will be erected around the restored area (site and borrow area) to protect revegetation efforts from gazing over a period of up to 10 years.

Short-Term Operation and Maintenance of Site Restoration Features.

Operation and maintenance (O&M) for restored excavation areas, obliterated temporary roads, and restored borrow areas include a vegetation survey once a year in late spring for up to 10 years and an erosion control inspection and maintenance survey once a year after the monsoon season for 10 years. Vegetation maintenance includes reseedings and removing weeds. Maintenance may include repairs to range fencing, adding soil to erosional features, and repairing water control berms.

On-Navajo Repository Closure and Long-Term Operation and Maintenance. Activities common to Alternatives 2 and 3 - Consolidation and Capping On-site include:

- Final grading, surface erosion controls, and revegetation of the on-site repository cap will be designed to limit visual impact by mimicking local terrain and using local soils and vegetation (Appendix B).
- Erosion controls on the cap may include biodegradable matting and wattles and using berms and ditches to direct run-on water around the repository.
- Temporary range fencing will be installed around restored areas during the revegetation period to stop livestock from disturbing the soil cover and revegetation efforts.
- Fencing will be installed around the repository to control or restrict grazing and access since overgrazing, livestock foot traffic, or vehicle traffic could damage the cap.

Land use controls would be required for waste placed in a repository to protect the response action. The form of the land use controls would likely be a land withdrawal or an environmental covenant, such as an easement to restrict future residential use or activities that would disturb the cap.

Annual inspection and maintenance of the repository covers will be conducted as specified in a long-term surveillance plan (10 CFR § 40.28) with inspection frequencies adjusted based on the cover stability and inspection findings. The annual inspection would consist of checking for erosion and animal burrows and verifying the integrity of erosion controls. Maintenance will consist of filling burrows, filling and grading eroded surfaces, clearing accumulated erosion materials, replanting vegetation, and repairing access roads. O&M costs were developed based on a 1,000-year duration (required under UMTRCA 40 CFR § 192[d] Part A) for the earthen covers placed on top of radiological waste contained within an on-site repository.

CERCLA Off-Site Rule - Alternatives that involve transportation off site for disposal or consolidation into a regional repository would require compliance with the CERCLA Off-Site Rule. In general, the Off-Site Rule requires that facilities that accept contaminated or hazardous wastes from a CERCLA site must follow all applicable regulations and laws (that is, they must be approved to take those wastes and be in compliance with the applicable federal, state, and local requirements to do so). The licensed disposal facilities considered for any alternatives involving off-site consolidation into a repository would be required to have existing approval under the Off-Site Rule.

4.2.1.2 Potential Unavoidable Impacts

Except for Alternative 1 (no action), each of the removal action alternatives would result in an overall improvement to the local environment. However, for Alternatives 2 through 4, unavoidable impacts are expected and include:

- Existing vegetation in the Quivira Tronox Mine areas is limited to scrub and grasses with a few small trees. Disturbed areas will be reclaimed after construction, but reestablishing the existing vegetation will take time.
- Inconvenience to local populations using Pipeline Canyon Road and Route 566; general disturbance to local residents from heavy equipment activity during the February to November construction period; and increased truck traffic on Pipeline Canyon Road, Route 566, and all other access roads near the Licensed Waste Facility. Generation of dust on

access roads would be minimized through spraying with water during construction and hauling activities. Noise will be limited to normal work hours to avoid disturbing local residents.

- Disruption of sensitive species and habitat during construction activities is not anticipated at the Quivira Tronox Mine site. If sensitive species are subsequently identified during a biological survey, the timing of construction activities will be adjusted to limit disturbance and biological monitoring will be conducted during construction activities.
- Cultural resources were not identified near the Quivira Tronox Mine during previous actions. However, a cultural resource specialist will be consulted during removal design to ensure that any proposed construction activities will avoid sensitive areas. Cultural resource monitors will be on site during construction activities to ensure resources are not disturbed.
- Disruption of wildlife and livestock access to the restored site for an estimated 10 years after completion of site work to establish and stabilize vegetation. Livestock access to repository covers may also be restricted, depending on cap design, to prevent damage to cap.
- Increased risk of traffic accidents and fatalities and greenhouse gas emissions because of the trucking of fill, cover material, and waste. As the haul distance increases, the potential risks also increase.

4.2.2 Description of Removal Action Alternatives

The following subsections present descriptions of the four removal action alternatives identified in Section 4.1.

4.2.2.1 Alternative 1: No Action

Under Alternative 1, radionuclide and metal COCs and contaminants of ecological concern (COECs) in the waste piles and surrounding soils would not be addressed. No land use controls, signage, range fencing, or barriers would be used to limit access at the mine. No removal or site stabilization activities would occur.

4.2.2.2 Alternative 2: Consolidate and Cap All Waste at Quivira CR-1

Alternative 2 includes waste disposal at one on-site repository at CR-1. The alternative is separated into two sub-alternatives, which are substantially similar: 2A and 2B. The difference between sub-alternative 2A and 2B is the inclusion of a synthetic liner in the cover system for sub-alternative 2B. The two options are discussed separately only where the liner inclusion choice influences the analysis. Geomorphic design would be implemented to enhance the aesthetics of the repository and improve erosion control. An example of a geomorphic design concept for CR-1 is shown in Appendix B.

Under Alternative 2, the RAOs would be accomplished through excavation, hauling, sorting, and consolidation of waste in a central repository located at CR-1; containment of waste in the on-site repository; and implementation and short-term O&M of site restoration measures and land use and

access controls to protect the repository and site restoration process. Site excavation and restoration elements common to alternatives are described in Section 4.2.1.1.

Approximately 314,500 cubic yards of waste from CR-1, CR-1E, and Kerr McGee Ponds would be hauled and consolidated at a repository at CR-1 covering approximately 26.9 acres (Figure 14). The Quivira CR-1 repository construction and O&M costs are based on the volume of waste contributed to the repository from Quivira CR-1, Quivira CR-1E, and Kerr McGee Ponds.

Site restoration activities include backfilling and grading of waste excavation areas, erosion controls, and revegetation. Site restoration activities are described further in Section 4.2.1.1. Post-removal visualizations of the restored Quivira Tronox Mine sites are included in Appendix B.

Removal Action Components

Additional information regarding individual components is provided in Section 4.2.1.1. Components of the removal action include:

- Rehabilitation and widening of the access road for haul trucks.
- Excavation of select waste from Quivira CR-1.
- Excavation of all waste from Quivira CR-1E.
- Excavation of all waste from Kerr McGee Ponds.
- Consolidation of contaminated soils to a single area on Quivira CR-1.
- Construction of an engineered cover over consolidated contaminated soils at one repository at CR-1.
- Site restoration at CR-1E with short-term erosion and stormwater controls, grading, and revegetation.
- Long-term cover maintenance at the CR-1 repository.
- Implementation of access controls, such as temporary fencing, berms or barricades on temporary access roads and benches to reduce ease of access for livestock over the short term, to allow for successful revegetation.
- Long-term cover maintenance at the CR-1 repository.
- O&M of surficial restoration areas

Cost Estimate

The costs of Alternative 2A and 2B are identical except for the additional cost of the liner for 2B. The total cost of 2A is estimated to be $41,101,000, and for 2B is estimated to be $41,845,000 (Appendix C, Tables C-1 and C 4). The costs for Alternative 2, both 2A and 2B, are the lowest among the alternatives. They are both considered good for cost.

4.2.2.3 Alternative 3: Consolidate and Cap All Waste Separately at Quivira CR-1 and Quivira CR-1E

Alternative 3 includes development of two mine waste repositories at the current locations of most of the waste: CR-1 and CR-1E. Alternative 3 is separated into two sub-alternatives, which are substantially similar: 3A and 3B. The difference between sub-alternative 3A and 3B is the inclusion of a synthetic liner in the cover system for sub-alternative 3B. The two sub alternatives are discussed separately only where the liner inclusion choice has an effect on the analysis. Geomorphic design would be implemented at both repository sites to enhance the aesthetics of the repositories and improve erosion control.

Under Alternative 3, the RAOs would be accomplished through excavation, hauling, and consolidation of waste at two repositories, one located at Quivira CR-1 and the other at Quivira CR-1E; containment of waste in the repository; implementation and short-term O&M of site restoration measures and land use and access controls to protect the repository and site restoration process (Figure 15). Site excavation and restoration elements common to alternatives are described in Section 4.2.1.1.

Approximately 840,000 cubic yards of waste from the CR-1 area will be consolidated in a repository at CR-1 covering approximately 26.9 acres; 103,000 cubic yards of waste from CR-1E will be consolidated in a repository at CR-1E covering approximately 8 acres. An additional 127,500 cubic yards of waste from the Kerr McGee Ponds area would be consolidated in the repository at CR-1. Site restoration activities include backfilling and grading of waste excavation areas, erosion controls, and revegetation (Figure 15). Temporary range fencing will be constructed around the repository to prevent grazing until vegetation becomes established. Site restoration activities are described further in Section 4.2.1.1. Post-removal visualizations of the restored Tronox Quivira Mines sites are included in Appendix B.

Removal Action Components

Additional information regarding individual components is provided in Section 4.2.1.1. Components of the removal action include:

- Excavation of select waste from Quivira CR-1.
- Consolidation of excavated Quivira CR-1 soils at Quivira CR-1.
- Excavation of select waste from Quivira CR-1E.
- Consolidation of excavated Quivira CR-1E soils at Quivira CR-1E.
- Excavation of select waste from Kerr McGee Ponds area.
- Consolidation of excavated Kerr McGee Pond soils at Quivira CR-1.
- Construction of engineered covers over repositories at both sites.
- Site restoration at both repositories with erosion and stormwater controls, grading, and revegetation.
- Long-term cover maintenance at both repositories.

- Implementation of access controls, such as berms or barricades on temporary access roads, benches, and temporary fencing to exclude grazing over the short term, to allow successful revegetation.
- Long-term cover maintenance at both repositories.
- Restoration of excavated surfaces.
- O&M of surficial restoration areas.

Cost Estimate

The costs of Alternative 3A and 3B are identical except for the additional cost of the liner for 3B. The total cost for 3A is estimated to be $46,557,000, and for 3B is estimated to be $47,413,000 (Appendix C, Tables C-1 and C 3). The costs for Alternative 3, both 3A and 3B, are second lowest among the alternatives. They are both considered average for cost.

4.2.2.4 Alternative 4: Reprocess and/or Dispose of All Mine Waste Off Site at a Licensed/Permitted Facility

Alternative 4 is broken into two sub-alternatives which are substantially similar: 4A and 4B. The difference is which off-site facility is chosen to receive the waste. Alternative 4A uses the White Mesa Mill facility in Blanding, Utah, while 4B uses the Clean Harbors facility in Deer Trail, Colorado. The on-site actions taken to address the waste are the same for each sub-alternative. The two sub-alternatives are discussed separately only where the choice of facility has an effect on the evaluation criteria of the removal action.

Under Alternative 4, the RAOs would be accomplished through excavation, transport, and off-Navajo Nation disposal of mine waste and contaminated soil. The site would be reclaimed through implementation of site restoration measures followed by short-term O&M of restored features and use of access controls to protect the site restoration process. Site excavation and restoration elements common to alternatives are described in Section 4.2.1.1.

Approximately 1,041,000 cubic yards of waste from the Quivira Tronox Mine would be hauled off the Navajo Nation and disposed of at a RCRA Class C hazardous waste or Class A low-level radioactive waste (LLRW) facility. The hauling of waste will comply with applicable state permitting requirements for the transport of radioactive materials.

Site restoration activities include backfilling and grading of waste excavation areas, erosion controls, and revegetation. Site restoration activities are described further in Section 4.2.1.1. Post-removal visualizations of the restored Quivira Mine sites are included in Appendix B.

The following facilities have licenses or permits that allow for acceptance of uranium mine waste:

- White Mesa Mill: Uranium mill and tailings disposal facility located 200 miles from the site.
- Clean Harbors, Deer Trail, Colorado: RCRA Class C hazardous waste disposal facility located 600 miles from the site.

The White Mesa Mill is regulated as a uranium mill and tailings disposal facility under NRC regulations in 10 CFR Part 40, Appendix A, by the State of Utah as an Agreement State under Atomic Energy Agency. The White Mesa Mill tailings disposal facility has a 3-million-ton capacity and is permitted an additional 4 million tons. At the time of this AAM preparation, the facility is in compliance with its State of Utah operating license, bonding, and the CERCLA Off-Site Rule. A change to the disposal facility could be selected in the action memorandum, if necessary. Coordination of waste batches for mill operations would require negotiation with USEPA, other potentially responsible parties, White Mesa Mill operators, and the Navajo Nation.

Although uranium mine ore material is classified as TENORM by USEPA, the source material license issued by the State of Utah allows the White Mesa Mill to process natural uranium ores. NRC has determined that a material is considered to be ore if there is a reasonable expectation that uranium can be recovered from the material even if it is low grade and not profitable, and the mill would receive a fee to process the material (Energy Fuels, Inc. 2018). Contaminated debris associated with the ore has been regulated as ore (NRC 2000 as cited in Energy Fuels, Inc. 2018). Based on these determinations, the White Mesa Mill can accept overburden, waste rock, proto ore, and other ore-related waste materials for processing through the mill. Resulting wastes associated with processing then become 11e(2) byproduct material and can be disposed of in the existing mill tailings disposal facility. If and when the mill and associated tailings disposal facility source material license is terminated, ownership of the tailings disposal facility will be transferred to DOE, which will be responsible for long-term surveillance, care, and maintenance.

The Clean Harbors, Waste Control Specialists, and Clive Operations RCRA Class C hazardous waste and LLRW disposal facilities are in compliance with NRC, Colorado, Texas, and Utah operating permits and the CERCLA Off-Site Rule. The Clean Harbors RCRA Class C hazardous waste facility was identified as the most cost-effective disposal facility and is located near Deer Trail, Colorado. In general, the CERCLA Off-Site Rule requires that facilities that accept contaminated or hazardous wastes from a CERCLA site must follow all applicable regulations and laws (that is, they must be approved to take those wastes and be in compliance with the applicable federal, state, and local requirements to do so). The licensed disposal facilities considered for any alternatives involving off-site disposal would be required to have existing approval under the Off-Site Rule.

Disposal at a licensed RCRA Class C hazardous waste or LLRW facility is a standard disposal method involving transport to and disposal at the applicable waste disposal facility. Licensed or permitted facilities are generally constructed to prevent the release of hazardous or radioactive materials and include engineered cells and liners that exceed requirements for municipal or commercial solid waste disposal facilities.

No TCLP metals results exceeded the toxicity characteristic levels. Therefore, it is not expected that the waste piles at the Quivira mine sites contain materials that would be designated as RCRA hazardous waste if disposed of at a RCRA-permitted disposal facility. No pretreatment of the waste is expected to be required before disposal.

Excavation and disposal of waste rock in an off-Navajo Nation RCRA Class C hazardous waste or Class A LLRW facility and implementation of run-on, erosion, and administrative controls would be performed as a single removal action. Figures 10 11show the proposed waste excavation and

restoration areas at the Quivira mines and Kerr McGee Ponds. For Alternative 4, waste will be transported to and disposed of at the White Mesa Mill or the Clean Harbors RCRA Class C hazardous waste disposal facility in Deer Trail, Colorado. The selected disposal facility could be changed in the action memorandum, if necessary. Implementation of Alternative 4 would involve the removal action components described below.

Removal Action Components

Additional information regarding individual components is provided in Section 4.2.1.1. Components of the removal action include:

- Excavation of Quivira CR-1, Quivira CR-1E, and Kerr McGee Pond area contaminated soils and step-out areas (as shown in Figures 10 11).
- Off-site reprocessing and disposal of excavated contaminated soils.
- Site backfill and restoration with erosion and stormwater controls, site grading, and vegetation establishment.
- Implementation of access controls, such as temporary fencing to exclude grazing over the short term, to allow successful revegetation.
- O&M of surficial restoration areas.

Cost Estimate

Alternative 4 overall has the highest costs of all the alternatives based on facility disposal fees and costs related to hauling distance. The difference in costs between Alternatives 4A and 4B are primarily from the different distances the waste would be hauled, as well as from differences between the waste processing fee for White Mesa Mill and tipping fees at the Clean Harbors facility in Deer Trail, Colorado. The total cost for 4A is estimated to be $276,343,000, and for 4B is estimated to be $550,579,000 (Appendix C, Tables C-1 and C 3). The costs for Alternative 4, both 4A and 4B, are highest among the alternatives. They are considered poor and very poor, respectively, for cost.

4.3 ANALYSIS OF ALTERNATIVES

As required by the NCP and described in the Guidance on Conducting Non-Time Critical Removal Actions under CERCLA (USEPA 1993), retained removal action alternatives are evaluated individually against the following three broad criteria: effectiveness, implementability, and cost. The qualitative evaluation criteria are described below.

Effectiveness Criterion

This criterion evaluates protectiveness and compliance with ARARs, along with short- and long-term effectiveness and permanence, and reduction in toxicity, mobility, and volume of waste. Effectiveness was rated from very poor to very good.

- **Overall Protection of Human Health and the Environment** – This threshold criterion evaluates whether each alternative provides adequate protection of human health and the environment. The assessment of overall protection draws on the evaluation of long-term effectiveness and permanence, short-term effectiveness, and compliance with ARARs.
- Evaluation of the overall protectiveness focuses on whether a specific alternative achieves adequate protection and how site risks posed through each pathway addressed by the AAM are eliminated, reduced, or controlled through treatment, engineering, or land use controls. Based on effectiveness and ARAR compliance, alternatives are either considered protective or not protective.
- **Compliance with ARARs** – This threshold criterion evaluates whether each alternative would meet the identified ARARs. The evaluation determines which requirements are applicable or relevant and appropriate to an alternative and how the alternative meets these requirements. Alternatives are either in compliance with ARARs or not in compliance.
- **Short-Term Effectiveness** – This criterion evaluates the effects that the alternative would have on human health and the environment during its construction and implementation phase. The evaluation includes both radiation risks from exposure to the contaminated soils and risks to the workers and communities from construction work, pollution, and traffic during implementation, and also takes into account the time necessary to complete the action. Short-term effectiveness was rated from very poor to very good.
- **Long-Term Effectiveness and Permanence** – This criterion evaluates the results of the removal action in terms of the risk remaining at the site after response objectives have been met. The primary focus of this evaluation is on the extent and effectiveness of the controls that may be required to manage the risk posed by wastes remaining at the site. Long-term effectiveness and permanence was rated from very poor to very good.
- **Reduction of Toxicity, Mobility, or Volume through Treatment** – This criterion addresses the statutory preference for remedies that employ treatment as a principal element by assessing the relative performances of treatment technologies for reducing toxicity, mobility, or volume of the contaminated media. Specifically, the analysis should examine the magnitude, significance, and irreversibility of each estimated reduction. Reduction of toxicity, mobility, or volume through treatment was rated from very poor to very good.

Implementability Criterion

This criterion evaluates the technical and administrative feasibility of implementing an alternative and the availability of required services and materials. Implementability was rated from very poor to very good.

- **Technical Feasibility** – This criterion takes into account construction considerations, demonstrated performance, adaptability to environmental conditions, and timing. Technical feasibility was rated from very poor to very good.
- **Availability of Required Services and Materials** – This criterion evaluates whether staff, equipment services, disposal locations, etc., are available in the necessary time frames for

construction and O&M activities. This criterion was combined with technical feasibility for this AAM.

- **Administrative Feasibility** – This criterion considers regulatory approval and scheduling constraints. Administrative feasibility was rated from very poor to very good.
- **Tribal, Supporting Agency, and Community Acceptance** – This criterion will not be addressed and a preferred alternative will not be selected in this draft AAM. These criteria will be addressed in the final AAM after initial input from tribal and supporting agencies. Community acceptance will be addressed in the action memorandum after the public review and comment period on the final AAM.

Cost Criterion

The types of costs assessed include the following:

- Capital costs, including both direct and indirect costs
- Annual post-removal site control costs (termed O&M within this AAM for brevity)
- Net present value of capital and O&M costs

In accordance with USEPA (1993, 2000b) guidance, engineering costs are estimates within plus 50 to minus 30 percent of the actual project cost (based on year 2021 dollars). Costs were rated from very poor to very good.

Cost Estimating Process

Cost estimates were prepared in accordance with USEPA (2000b) guidelines using engineer's estimates, RSMeans 2021 cost estimating software, and vendor quotes. Farmington, New Mexico, was used as the reference city in the RSMeans software to estimate for labor, equipment, and supplies where applicable. In accordance with USEPA (1993, 2000b) guidance, the engineering costs are estimates that are expected to be within plus 50 to minus 30 percent of the actual project cost (based on year 2021 dollars). Only the rolled up construction and capital costs, short-term O&M costs for site restoration, long-term O&M costs for repositories, and net present values are presented for each alternative. Cost details and assumptions are presented in Appendix C.

Cost estimating was conducted using a crew time and materials (T&M) approach. A crew T&M approach used the time required for a crew to accomplish an activity based on a realistic production rate for site conditions. Alternatively, a unit cost approach uses RSMeans unit costs for construction based on cubic yard, linear foot, and square foot quantities, which would not be realistic because of the specific equipment needs and low production rates in remote, steep slope work areas. Other construction-related costs were identified and included in the cost approach, including mobilization and demobilization, contractor site overhead, travel and lodging, third-party oversight, Navajo Nation tax for on-Navajo Nation activities, and a 20 percent contingency. Non-construction-related costs required before and during construction activities were also identified and included in the cost approach, including design, planning, resource surveys, confirmation sampling, and reporting.

Contingency costs for construction are based on the extra time, equipment, and personnel required to safely work with radioactive materials; remote location of the site; differences in labor pool costs between RSMeans estimating software reference cities and the project area; and potential for changes in material and transportation costs. Changes in the cost elements are likely as commodity prices change and new information and data are collected during the engineering design and construction pre-bid and walk-through meetings.

The needs for short- and long-term post-removal site control or O&M costs were identified, including the short-term need for site restoration for a period of 10 years to address any erosion and revegetation efforts and the long-term need for cap and cover maintenance for a period of 1,000 years for on-site consolidation and capping for on-Navajo Nation repository alternatives. Project duration (10 years versus 1,000 years) varies depending on the alternative being evaluated and will be addressed in the cost discussion for each alternative.

The net present value of each removal action alternative provides the basis for the cost comparison. The net present value represents the amount of money that, if invested in the initial year of the removal action at a given interest rate, would provide the funds required to make future payments to cover all O&M costs associated with the removal action over its planned life.

To assess the required funds to be set aside for implementing O&M activities in the future, this AAM uses a 3.5 percent discount rate, which is the 30-year rolling average of the annual discount rates for varying streams of payments as provided by the Office of Management and Budget (OMB) (2020). The 3.5 percent discount rate would require more money to be set aside for future O&M costs than the historical average of 7 percent referenced in USEPA (1993) guidance.

4.3.1 Alternative 1: No Action

4.3.1.1 Effectiveness

The effectiveness rating for Alternative 1 is **Very Poor** based on the following discussion.

Overall Protection of Public Health and the Environment (Rating: Not Protective) – The No Action alternative would not achieve RAOs. This alternative would not minimize potential exposure to or transport of COCs or COECs from the site or control radiation and physical hazards at the site. This alternative would not reduce risk to human health or the environment. Therefore, protection of human health and the environment would not be achieved under the No Action alternative.

Compliance with ARARs (Rating: Not Applicable) – Under this alternative, there are no ARARs with which to comply per CERCLA § 121(d). ARARs provide specifications on the degree of cleanup and are, therefore, not pertinent if no cleanup occurs.

Short-Term Effectiveness (during Removal Action) (Rating: Very Good) – Alternative 1 has no action, so no short-term risks would exist for the community or workers from construction activities. However, threats to human and ecological receptors would persist in the short term. Because no construction activities would occur, no additional energy use, air pollution, water use, waste and materials management, and ecosystem protection requirements would be triggered. No

additional traffic volume or potential accidents and fatalities associated with construction would occur.

Long-Term Effectiveness and Permanence (after Removal Action) (Rating: Very Poor) –

The No Action alternative does not offer any long-term effectiveness and permanence in reducing potential risks to human and ecological receptors. No controls or long-term measures would be implemented to control COCs or COECs at the site other than routine maintenance consisting of erosion and stormwater control, vegetation maintenance, and site cover and fencing repair.

This alternative would not provide control through treatment of soils with concentrations of Ra-226 above the action level or reduce volume or mobility of contaminants. The resultant risks associated with the No Action alternative would be similar to those that existed at the time of the RSE field investigations with no increased protection of human health and the environment.

This alternative would not alter the potential exposure to, or transport of, contaminated soils from the Quivira mines. Surface water discharge from the Site to both Unnamed Arroyo #2 and Pipeline Canyon Arroyo would have continued potential to transport contaminated soils to the downstream watershed. Nearby residents would continue to be potentially exposed to wind-borne and water-borne contaminants. Domestic livestock and their owners/caretakers would potentially be exposed to surface soil contamination through direct contact and dust inhalation.

4.3.1.2 Implementability

The implementability rating for Alternative 1 is **Very Good** based on the following discussion.

Technical Feasibility and Availability of Services and Materials (Rating: Very Good) – Alternative 1 is readily implementable because no construction is involved. This alternative would not impact the ability to conduct removal or remedial actions in the future. No services or materials would be needed to implement Alternative 1.

Administrative Feasibility (Rating: Very Good) – Alternative 1 is administratively feasible as taking no action is feasible.

4.3.1.3 Costs

Alternative 1 involves no removal activities and no legal or administrative activities. Therefore, Alternative 1 would incur no cost and would rate as **Very Good**.

4.3.2 Alternative 2: Consolidate and Cap all Waste at Quivira CR-1

4.3.2.1 Effectiveness

The effectiveness rating for Alternative 2 is **Good** based on the following discussions

Overall Protection of Public Health and the Environment (Rating: Protective) –

Alternative 2 is protective of human health and the environment as the contaminated soils exceeding the action level at Quivira CR-1, Quivira CR-1E, and Kerr McGee Ponds area would be consolidated and covered in a single capped area located at Quivira CR-1. Both engineered covers (including and excluding a synthetic liner) are physical barriers that offer protection from water infiltration and percolation into the contaminated soils, protect groundwater resources, and provide adequate shielding from ionizing radiation to protect human health and the environment. The covers would prevent direct contact between the wastes and the public or the environment. Proper construction and design of the cover includes the establishment of vegetation, which reduces or prevents erosion. Proper stormwater controls and maintenance of the cover would prevent release of the contaminated soils back into the environment. The current waste rock stockpile at Quivira CR-1 would remain in place and additional waste material would be consolidated at that location.

Compliance with ARARs (Rating: In Compliance) –

Alternative 2 would meet federal, state, and Navajo Nation ARARs for the Quivira mines. Common ARARs for Alternative 2 are found in Tables 3-5.

Short-Term Effectiveness (during Removal Action) (Rating: Good) –

Short-term effectiveness is rated **Good** for Alternative 2 because only a portion of the waste would be disturbed and there would be transport of waste near the community. The primary considerations for short-term effectiveness are protection of the community, workers, and environmental impacts during and shortly after implementation. Alternative 2 involves excavation and material transfer within and between Quivira CR-1E and the Kerr McGee Ponds area, and Quivira CR-1; stockpile development/management; loading of haul trucks; waste hauling; and site restoration activities.

- **Protection of the Community during Removal Action** – Dust control measures, such as water spraying, would be used during excavation, on-site repository construction, waste compaction, and capping of the waste. However, some dust generation is unavoidable. Air monitors would be placed around the construction zone at the site and repository to measure potential risks to the community.

  Dump trucks hauling the waste between sites would be covered and secured. Truck traffic would be coordinated under a transportation plan for routes, times of operation, and on-site traffic rules. Attempts would be made to minimize trucking across Navajo Nation roadways. Emergency spill containment and cleanup contingencies would be included in the transportation plan to address material spills. Alternative 2 is estimated to cause a risk of an additional 0.01 traffic fatalities and create 1,300 metric tons of greenhouse gas (carbon dioxide equivalent [CO2e]) emissions.

- **Protection of Workers during Removal Action** – Heavy equipment would be used to clear and grub, excavate, transfer, load, and grade impacted materials. Potential exposure and protection procedures for workers engaged in earth-moving activities would be addressed in detail under a site safety and health plan. During excavation and material handling activities, measures would be taken to reduce fugitive dust emissions and

associated impacts to workers. Water would need to be obtained from an off-site source for dust control, and workers in the controlled area would don the appropriate safety equipment and implement safety practices such as air monitoring. Work areas would be secured (for example, marked or fenced) to control access to authorized personnel only. Short-term risks of physical injury would exist for site workers during construction, primarily related to operating equipment during access road construction, waste excavation, site restoration, and repository construction. All workers will be required to wear personal dosimeters to ensure that radiation exposure does not exceed Occupational Safety and Health Administration (OSHA) limits.

- **Environmental Impacts** – Even with control measures, short-term environmental impacts could occur from excavation and placement of waste in an on-site repository. These environmental impacts may include sedimentation of local drainages, residual track-in and track-out effects of soil and mud, noise, disturbed vegetation, and dust generation. However, the threat to the environment is low because the waste rock could be readily cleaned up within 3 years. In addition, revegetation will expedite the return of native flora. The short-term threat posed by exposure to uranium and radionuclides would be minimal.
- **Time Until Removal Action Objectives Are Achieved** – The time period to implement Alternative 2 is estimated to be 2 years and 1 month following 2 years of design, planning, and permitting. Alternative 2 is estimated to cause a risk of 0.01 additional traffic fatalities and create 1,800 metric tons of greenhouse gas (CO2e) emissions. The sub-alternatives are considered to be equal for short-term effectiveness. Construction may be extended depending on schedule-limiting factors such as monsoon rains and snowfall.

Long-Term Effectiveness and Permanence (after Removal Action) (Rating: Good) – Long-term effectiveness of this alternative is rated **Good** for both 2A and 2B. HELP modeling shows no significant difference in the infiltration and percolation of precipitation into the waste in either cover scenario. Landfills and mines around the country are often closed on site with covers and a maintenance plan. Cover maintenance is a well-established practice. Since contaminated soils would remain on the Site, potential exposure reductions to those accessing the Site would be dependent on maintenance of the cover. Drainage features and stormwater controls would be included in the design, so that surface water would be diverted from the capped area and aid in prolonging the integrity of the cover. Alternative 2 is expected to effectively mitigate the long-term effects on potential human and ecological receptors as long as the cover is maintained.

The cover for both Alternatives 2A and 2B will be the engineered store-and-release earthen cover . The difference between the two sub-alternatives is that Alternative 2B includes a 40-mil HDPE top liner as part of the cover. Both engineered earthen covers will meet the RAOs, ARARs, and be protective of human health and the environment for 1,000 years.

4.3.2.2 Implementability

The implementability rating for Alternative 2 is **Good** based on the following discussion.

Technical Feasibility and Availability of Services and Materials (Rating: Good) –

Alternative 2 is technically feasible and would use conventional techniques, materials, and labor for the excavation and associated activities. Quivira CR-1, Quivira CR-1E, and the Kerr McGee

Ponds area are all readily accessible. Excavation would be scheduled and performed to maximize direct loading and promote worker and public safety. Engineering controls for fugitive dust and site monitoring would be used to minimize exposure of sensitive receptors to radioisotopes.

Administrative Feasibility (Rating: Good) –

Alternative 2 is administratively feasible. The contaminated soils may be transported within or between Quivira CR-1, Quivira CR-1E, and the Kerr McGee Ponds area for consolidation. Transportation permits would not be necessary. Construction of an engineered cover would not require permitting because contaminated soils are considered low-level radioactive materials and are not a RCRA hazardous waste. In addition, permits are not required for on-site CERCLA actions. On-site CERCLA actions must comply with the substantive requirements of any state, tribal or local permit, but not the administrative requirements. Community and stakeholder engagement may be significant because the waste will remain on the Navajo Nation.

4.3.2.3 Costs

Overall, Alternative 2 has the lowest costs of all the alternatives (besides Alternative 1 - No Action) mainly because of lower costs for local hauling and disposal in an on-site repository even after both short-term (10-year) site restoration O&M costs and long-term (1,000-year) on-site repository O&M costs are considered. The overall effectiveness of Alternative 2 is rated **Good** (after the **Good** rating for short-term effectiveness is combined with the **Good** rating for long-term effectiveness and permanence). The low costs compared with the **Good** overall effectiveness rating means that Alternative 2 is cost effective, and the cost rating is **Good**.

The costs of Alternative 2A and 2B are identical except for the additional cost of the liner for 2B. The total cost of 2A is estimated to be $41,101,000, and for 2B is estimated to be $41,845,000 (Appendix C, Tables C-1 and C-2). The overall effectiveness, with good short-term and long-term effectiveness, is compared to the cost to determine whether the removal action is cost-effective. The costs for Alternative 2, both 2A and 2B, are the lowest among the alternatives. They are both considered cost-effective and rated as **Good** for cost.

A breakdown of the major cost categories associated with implementing Alternative 2 is presented below. Detailed cost estimates are provided in Appendix C and Tables C-1 and C-2.

Cost Component	Alternative 2A	Alternative 2B
Excavated Surface Area (Acres)	63.9	63.9
Excavated Volume (Cubic Yards)	314,500	314,500
Direct Capital Costs		
Field Overhead and Oversight	$4,072,000	$4,072,000
General Site Work	$158,000	$158,000
Earthwork	$23,578,000	$24,113,000
Transportation and Disposal	$0	$0

Cost Component	Alternative 2A	Alternative 2B
Subtotal Direct Capital Costs	$27,808,000	$28,343,000
Indirect Capital Costs	$5,840,000	$5,952,000
Total Capital Costs	$38,695,200	$39,439,250
O&M Costs		
Present Worth of 1,000 Years O&M	$1,924,526	$1,924,526
Contingency Allowance (25%)	$481,132	$481,132
Total Present Worth O&M Cost	$2,406,000	$2,406,000
Total Cost	**$41,101,000**	**$41,845,000**

Notes:
O&M Operation and maintenance

4.3.3 Alternative 3: Consolidate and Cap All Waste Separately at Quivira CR-1 and Quivira CR-1E

4.3.3.1 Effectiveness

The effectiveness rating for Alternative 3 is **Good** based on the following discussion.

Overall Protection of Public Health and the Environment (Rating: Protective) –

Alternative 3 is protective of human health and the environment as the contaminated soils exceeding the action level at Quivira CR-1, Quivira CR-1E, and Kerr McGee Ponds would be consolidated and covered in separate repositories at Quivira CR-1 and Quivira CR-1E. Both engineered covers (including and excluding a synthetic liner) are physical barriers that offer protection from water infiltration and percolation into the contaminated soils, protect groundwater resources, and also provide adequate shielding from ionizing radiation to protect human health and the environment. Both covers would prevent direct contact between the wastes and the public or the environment. Proper construction and design of the covers includes the establishment of vegetation, which reduces or prevents erosion.

Proper stormwater controls and maintenance of the cover would prevent release of the contaminated soils back into the environment. Radon ventilation systems would be used to prevent exposure in nearby residences, if necessary. The current waste rock stockpile at Quivira CR-1 would remain in place and additional waste material consolidated at that location.

Compliance with ARARs (Rating: In Compliance) –

Alternative 3 would meet federal, state, and Navajo Nation ARARs for the Quivira mines. Common ARARs across Alternatives 2 through 4 are found Tables 3-5.

Short-Term Effectiveness (during Removal Action) (Rating: Good) – The short-term impacts to the community, workers, and environment under Alternative 3 are as described below.

- **Protection of the Community during Removal Action** – Dust control measures, such as water spraying, would be used during excavation, repository construction, waste compaction, and capping of the waste. However, some dust generation is unavoidable. Air monitors would be placed around the construction zone at the site and repository to measure potential risks to the community.
- The primary considerations for short-term effectiveness are protection of the community, workers, and environmental impacts during and shortly after implementation. This alternative disturbs the least amount of waste, requires the least amount of hauling soils through communities and on highways, and has the shortest overall duration. However, it is not without challenges. While only a portion of the waste would be disturbed and there would be minimal transport of waste near the community, sourcing water and effectively controlling dust will be challenging. The nearest potential water source is at least 10 miles away, and the sustainable productivity of the well is unknown.
- **Protection of Workers during Removal Action** – On-site workers would require standard 40-hour OSHA hazardous materials training and radiation awareness training and would be adequately protected by using appropriate personal protective equipment and following safe work practices and standards. Radiation exposure monitoring would be required. Short-term impacts to air quality in the surrounding environment may occur during excavation, repository construction, and placement of mine waste in the regional repository. Dust suppression and monitoring would be required to ensure that workers are not exposed to or inhale radionuclides in particulates. Decontamination of workers and equipment would be required before exiting the site. Potential exposure and protection procedures for workers engaged in earth-moving activities would be addressed in detail under a site safety and health plan. During excavation and material handling activities, measures would be taken to reduce fugitive dust emissions and associated impacts to workers although sourcing water may be an issue. Water would need to be obtained from a developed on-site source or off-site source for dust control, and workers in the controlled area would don the appropriate safety equipment and implement safety practices such as air monitoring. Work areas would be secured (for example, marked or fenced) to control access to authorized personnel only.

  Short-term risks of physical injury would exist for site workers during construction, primarily related to operating equipment during access road construction, waste excavation, site restoration, and repository construction. All workers will be required to wear personal dosimeters to ensure that exposure does not exceed OSHA limits.
- **Environmental Impacts** – Even with control measures, short-term environmental impacts could occur. These environmental impacts may include residual track-in and track-out effects of soil and mud, noise, disturbed vegetation, and dust generation. However, the threat to the environment is low because the mine waste could be cleaned up within 3 years. In addition, revegetation will expedite the return of native flora. The short-term threat posed by exposure to uranium and radionuclides would be minimal.
- **Time Until Removal Action Objectives Are Achieved** – The time period to implement Alternative 3 is estimated to be 2 years and 6 months following 2 years of design, planning, and permitting. Alternative 3 is estimated to cause a risk of 0.01 additional traffic fatalities and create 1,600 metric tons of greenhouse gas (CO2e) emissions. The sub-alternatives are

considered to be equal for short-term effectiveness. Construction may be extended depending on schedule-limiting factors such as monsoon rains and snowfall.

Long-Term Effectiveness and Permanence (after Removal Action) (Rating: Good) –

Long-term effectiveness of this alternative is rated **Good** for both 3A and 3B. HELP modeling shows that there is not a significant difference in the amount of infiltration and percolation of water through the waste for either engineered cover design (omitting or using a synthetic liner component). Landfills and mines around the country are routinely closed on site with covers and a maintenance plan. Cover maintenance is a well-established practice. Since contaminated soils would remain on the Site, potential exposure reductions to those accessing the Site would be dependent on maintenance of the cover. Drainage features and stormwater controls would be included in the design, so that surface water would be diverted from the capped areas and aid in prolonging the integrity of the cover. Alternative 3 is expected to effectively mitigate the long-term effects on potential human and ecological receptors as long as the cover is maintained.

Both engineered earthen covers will meet the RAOs, ARARs, and be protective of human health and the environment for 1,000 years.

4.3.3.2 Implementability

The implementability rating for Alternative 3 is **Good**, based on the following discussions.

4.3.3.3 Technical Feasibility and Availability of Services and Materials (Rating: Good) – Alternative 3 (for both sub-alternatives 3A and 3B) is technically implementable and would use conventional techniques, materials, and labor for the excavation and associated activities. Quivira CR-1, Quivira CR-1E, and the Kerr McGee Ponds area are all readily accessible. Excavation would be scheduled and performed to maximize direct loading and ensure worker and public safety. Engineering controls for fugitive dust and site monitoring would be used to minimize exposure of sensitive receptors to radioisotopes.

4.3.3.4 Administrative Feasibility (Rating: Average)

Alternative 3 is administratively implementable. The contaminated soils may be transported within Quivira CR-1 and Quivira CR-1E for consolidation and from the Kerr McGee Ponds area to CR-1. Transportation permits would not be necessary. Construction of an engineered cover would not require permitting because contaminated soils are considered low-level radioactive materials and are not a RCRA hazardous waste. In addition, permits are not required for on-site CERCLA actions. On-site CERCLA actions must comply with the substantive requirements of any state, tribal or local permit, but not the administrative requirements. Community and stakeholder engagement may be significant because the waste will remain on the Navajo Nation.

4.3.3.5 Costs

Overall, Alternative 3 has the second lowest costs of all the alternatives (besides Alternative 1 - No Action) because of lower costs for local hauling and disposal in two repositories even after both short-term (10-year) site restoration O&M costs and long-term (1,000-year) repository O&M costs are considered. The overall effectiveness of Alternative 3 is rated **Good** (after the **Good** rating for

short-term effectiveness is combined with the **Good** rating for long-term effectiveness and permanence). The low costs compared with the **Good** overall effectiveness rating means that Alternative 3 is cost effective, and the cost rating is **Average (**because Alternative 2 costs less).

The costs of Alternative 3A and 3B are identical except for the additional cost of the liner for 3B. The total cost for 3A is estimated to be $46,557,000, and for 3B is estimated to be $47,413,000 (Appendix C, Tables C-3 and C-4). The overall effectiveness (**Good** long-term and short-term ratings) is compared to the cost to evaluate whether the removal action is cost effective. The costs for Alternative 3, both 3A and 3B, are second lowest among the alternatives. They are both considered cost-effective and rated as **Average** for cost.

A breakdown of the major cost categories associated with implementing Alternative 3 is presented below. Detailed cost estimates are provided in Appendix C Tables C-3and C-4.

Cost Component	Alternative 3A	Alternative 3B
Excavated Surface Area (Acres)	63.9	63.9
Excavated Volume (Cubic Yards)	242,000	242,000
Direct Capital Costs		
Field Overhead and Oversight	$4,519,000	$4,519,000
General Site Work	$158,000	$158,000
Earthwork	$26,787,000	$27,402,000
Transportation and Disposal	$0	$0
Subtotal Direct Capital Costs	$31,464,000	$32,079,000
Indirect Capital Costs	$6,607,000	$6,737,000
Total Capital Costs	$43,781,650	$44,638,400
O&M Costs		
Present Worth of 1,000 Years O&M	$2,220,000	$2,220,000
Contingency Allowance (25%)	$555,000	$555,000
Total Present Worth O&M Cost	$2,775,000	$2,775,000
Total Cost	$46,557,000	$47,413,000

Notes:
O&M Operation and maintenance

4.3.4 Alternative 4: Reprocess and/or Dispose of All Mine Waste Off Site at a Licensed/Permitted Facility

4.3.4.1 Effectiveness

The effectiveness rating for Alternative 4 is **Average** based on the following discussion.

Overall Protection of Public Health and the Environment (Rating: Protective) –

This alternative would protect human health and the environment as the contaminated soils exceeding the action level at Quivira CR-1, Quivira CR-1E, and Kerr McGee Ponds area would be removed for off-site transportation and disposal at a licensed and permitted facility designed to manage radioactive waste. This alternative would significantly minimize potential long-term exposure to contaminated soils from the Quivira mines. Potential short-term exposures during excavation, transport, and at the final disposal site would be managed through engineering controls.

From an COPC exposure perspective, each of the three Alternative 4 actions is protective of human health and the environment. However, highway fatality calculations indicate shipping soils to Deer Trail for disposal have a significant risk of a highway traffic fatality. Chemically, disposal at Deer Trail is protective, but physically this may not be the case. This is discussed further in the evaluation of short-term effectiveness.

Compliance with ARARs (Rating: In Compliance) –

Alternative 4 would meet federal, state, and Navajo Nation ARARs for the Quivira mines.

Common ARARs across Alternatives 2 through 4 are found in Tables 3 through 5.

Short-Term Effectiveness (during Removal Action) (Rating: Very Poor) – The short-term impacts to the community, workers, and environment under Alternative 4 are as described below.

- **Protection of the Community during Removal Action** – Dust control measures, such as water spraying, would be used during waste excavation and loading for off-site transport. However, some dust generation is unavoidable. Air monitors would be placed around the construction zone to measure potential risks to the community. Trucks hauling equipment and supplies would also add traffic and noise.

  Bulk carriers hauling the containerized wastes off site would be covered, secured, and weighed to document compliance with total and axle load limits. Truck traffic would be coordinated under a transportation plan for routes, times of operation, and on-site traffic rules. Emergency spill containment and cleanup contingencies would also be included in the transportation plan.

- **Protection of Workers during Removal Action** – On-site workers would require standard 40-hour OSHA hazardous materials training and radiation awareness training and would be adequately protected by using appropriate personal protective equipment and following safe work practices and standards. Radiation exposure monitoring would be required. Short-term impacts to air quality in the surrounding environment may occur during

excavation and loading of waste for off-site transport. Dust suppression and monitoring would be required to ensure that workers are not exposed to or inhale radionuclides in particulates. Decontamination of workers and equipment would be required before exiting the site.

Under each sub-alternative heavy equipment would be used to clear and grub, excavate, transfer, load, transport waste to a facility as well as reclaim the site by grading the footprints of the removal areas, applying growth media, and applying native seed and soil amendments for local vegetation establishment. Potential exposure and protection procedures for workers engaged in these activities would be addressed in detail under a site safety and health plan. During excavation and material handling activities, measures would be taken to reduce fugitive dust emissions and associated impacts to workers. Water would be imported for dust control, and workers in the controlled area would don the appropriate safety equipment and implement safety practices such as air monitoring. Work areas would be secured (for example, marked or fenced) to ensure access by authorized personnel only.

- **Environmental Impacts** – Even with control measures, short-term environmental impacts could occur. These environmental impacts may include residual track-in and track-out effects of soil and mud, noise, disturbed vegetation, and dust generation. However, the threat to the environment is low because the mine waste could be cleaned up within 8 to 17 years depending on the sub-alternative. In addition, revegetation will expedite the return of native flora. The short-term threat posed by exposure to uranium and radionuclides would be minimal.
- **Time Until Removal Action Objectives Are Achieved** – Excavation, hauling off-Navajo Nation, and disposal of waste at either the White Mesa Mill site in Utah or the Clean Harbors RCRA Class C hazardous waste disposal facility would meet preliminary RAOs in the short term. The construction time required to achieve RAOs for Alternative 4 would be approximately 8 to 17 years depending on the sub-alternative. Construction may be extended depending on schedule-limiting factors such as truck availability, monsoon rains, and snowfall.

Long-Term Effectiveness and Permanence (after Removal Action) (Rating: Very Good) –

Long-term effectiveness for each sub-alternative of this alternative is rated **Very Good**. Since all contaminated soils would be excavated and removed from the Site, potential exposure reductions to receptors accessing the Site would be permanent. Long-term maintenance is lowest under this alternative because it focuses on native vegetation re-establishment only and does not require repository maintenance. Alternative 4 is expected to effectively mitigate the long-term effects on potential on-site human and ecological receptors.

4.3.4.2Implementability

The implementability rating for Alternative 4 is **Very Good** based on the following discussion.

Technical Feasibility and Availability of Services and Materials (Rating: Very Good) – Alternative 4 is overall rated **Very Good** for technical feasibility and would use conventional techniques, materials, and labor for the excavation and associated activities. Quivira CR-1, Quivira CR-1E, and the Kerr McGee Ponds are all readily accessible. Excavation would be scheduled and

performed to maximize direct loading and ensure worker and public safety. Engineering controls for fugitive dust and site monitoring would be used to control potential exposures to sensitive receptors. Profiling and manifesting of the material would be done in coordination with the transporters and the off-site mill facility or landfill.

Alternative 4 consists mainly of simple earthwork and material hauling. Alternative 4 requires a contractor experienced in the excavation of mine waste, drainage channel reconstruction, biodegradable erosion control matting and wattles, and stormwater diversion berms and ditches, hazardous substances, and traffic, dust, and stormwater management. The equipment required for the work is readily available and consists of scrapers, loaders, dozers, crushing/screening plant for borrow materials, and on-highway haul trucks. The transport of waste to the White Mesa Mill would have a truck cycle time of 1 day while disposal at the Deer Trails hazardous waste landfill will increase the cycle time for trucks to approximately 3 days, resulting in the need for more trucks or increased construction time.

Construction and environmental monitoring equipment and services are all readily available. Labor would be available both on the Navajo Nation and in the regional market. Access to a sufficient volume of water for dust suppression is necessary, which would be obtained through construction of an on-site water well or connection with a nearby NTUA water pipeline.

Sources of borrow material are adequate to meet the needs for fill and topsoil for restoration after excavation. Riprap will need to be imported from Durango, Colorado, to meet engineering specifications for armoring drainage channels.

Alternative 4 would be completed as a single phase, and no future removal actions are anticipated. Long-term monitoring and maintenance would not be required; however, short-term maintenance of erosional controls and revegetation efforts would be required. Run-on water control berms, drainage ditches, and sediment detention basins would be repaired as necessary. Temporary range fencing would also be checked and repaired as necessary.

The White Mesa Mill and Clean Harbors RCRA Class C hazardous waste disposal facility are currently in compliance with their operating permits and with the CERCLA Off-Site Rule. Because all waste would be disposed of off site, reliance on the disposal capacity of the White Mesa Mill or Clean Harbors facility brings uncertainty to the availability of services at the time of the removal action. A change to the disposal facility could be selected in the action memorandum, if necessary.

Administrative Feasibility (Rating: Good) – Implementation of Alternative 4 would require coordination between USEPA, NNEPA, and NAMLRD to address federal and tribal ARARs, but federal permits for on-site actions under CERCLA are not required. General construction permits and environmental reviews may be required from the Navajo Nation. Finally, negotiations with the Navajo Nation or other landowners with potential off-site soil borrow sources would need to be conducted and agreements crafted.

Off-site disposal of materials from a CERCLA site must comply with the CERCLA Off-Site Rule. The White Mesa Mill and Clean Harbors RCRA Class C hazardous waste disposal facilities currently have approval under the Off-Site Rule and would need to maintain such approval.

The entity responsible for the short-term surveillance of site restoration features would maintain various plans and conduct periodic inspections and reviews, including:

- A stormwater pollution prevention plan overseen by NNEPA (to verify that restoration is protective of surface water quality)

Alternatives 4A and 4B are rated **Good** for administrative feasibility since shipping of waste (ore for reprocessing) is fairly common and would only require scheduling and obtaining the necessary permits. All contaminated soil is anticipated to be accepted by permitted facilities.

4.3.4.3 Costs

Alternative 4 overall has the highest costs of all the alternatives because of facility disposal fees. The difference in costs between Alternatives 4A and 4B are primarily from the different distances the waste would be hauled and the associated costs, as well as from the waste processing fee for White Mesa Mill. Detailed cost estimates are located in Appendix C, Tables C-5 and C-6.

The overall effectiveness of Alternative 4 is rated **Average**, from combining the **Very Poor** short-term and **Very Good** long-term effectiveness and permanence. The high costs compared with the **Average** overall effectiveness rating mean Alternative 4 is not cost-effective, and the cost rating for Alternative 4A is **Poor** and 4B is **Very Poor**.

A breakdown of the major cost categories associated with implementing Alternative 4 for each site is presented below. Detailed cost estimates are provided in Appendix C Tables C-5 and C-6.

Cost Component	Alternative 4A	Alternative 4B
Excavated Surface Area (Acres)	63.9	63.9
Excavated Volume (Cubic Yards)	1,041,000	1,041,000
Direct Capital Costs		
Field Overhead and Oversight	$10,338,000	$18,453,000
General Site Work	$158,000	$158,000
Earthwork	$14,997,000	$15,420,000
Transportation and Disposal	$191,485,600	$386,874,300
Subtotal Direct Capital Costs	$216,979,000	$420,905,000
Indirect Capital Costs	$22,319,000	$56,859,000
Total Capital Costs	$275,192,700	$549,428,600
O&M Costs		
Present Worth of 1,000 Years O&M	$920,336	$920,336
Contingency Allowance (25%)	$230,084	$230,084
Total Present Worth O&M Cost	$1,150,000	$1,150,000
Total Cost	**$276,343,000**	**$550,579,000**

Notes:
O&M Operation and maintenance

5.0 COMPARATIVE ANALYSIS OF ALTERNATIVES

This section presents the approach for the comparative analysis of alternatives and a summary of the analysis. The comparative analysis includes the evaluation of the relative effectiveness, implementability, and cost between alternatives.

5.1 COMPARATIVE ANALYSIS APPROACH

The final step of this AAM is to conduct a comparative analysis of the removal action alternatives. This analysis evaluates each alternative's strengths and weaknesses relative to the other alternatives in achieving RAOs. The comparative analysis ranks the effectiveness, implementability, and cost of each alternatives as very poor, poor, average, good, or very good for each criterion. An explanation of the evaluation and ranking criteria are presented in Section 4.3. Once completed, the analysis will be used to support risk managers and stakeholders in the selection of a preferred removal action alternative for the Quivira Tronox Mine sites. Tribal, supporting agency, and public acceptance will be evaluated after stakeholder comments have been received on this AAM.

In addition, based on USEPA (2016) guidance, five key elements in greener cleanup activities should be considered throughout the remedy selection process. USEPA's (2012) five key elements are to:

- Minimize total energy use and maximize renewable energy use
- Minimize air pollutants and carbon dioxide equivalent emissions
- Minimize water use and negative impacts to water resources
- Improve materials management and waste reduction efforts by reducing, reusing, or recycling whenever feasible
- Protect ecosystem services

5.2 SUMMARY OF ANALYSIS

All alternatives except for Alternative 1 meet the threshold criterion of protectiveness of public health and the environment. Table 7 summarizes the comparative rating of alternatives.

5.2.1 Effectiveness

Effectiveness comprises two threshold criteria (protectiveness and compliance with ARARs), and includes short- and long-term effectiveness and permanence of the remedy. Overall effectiveness is rated **Poor** for Alternative 1, **Good** for Alternative 2, **Good** for Alternative 3, and **Good** for Alternative 4.

5.2.1.1 Overall Protectiveness of Human Health and the Environment

All alternatives except for Alternative 1 are protective of public health and the environment.

5.2.1.2 Compliance with ARARs

All alternatives except for Alternative 1 would be performed in compliance with federal and tribal ARARs identified in Tables 3, 4, and 5.

5.2.1.3 Short-Term Effectiveness (during Removal Action)

Short-term effectiveness comprises four criteria: protection of the community and workers during the removal action, environmental impacts, and time to meet RAOs. Overall short-term effectiveness is rated **Very Good** for Alternative 1, **Good** for Alternative 2, **Good** for Alternative 3, and **Very Poor** for Alternative 4.

Protection of the Community during Removal Action

Alternatives 2 and 3 (a haul route away from the community) are rated **Good**. These alternatives create the least traffic and dust impacts to the community as truck traffic would only be increased on the main access road to transport construction materials for excavation and on-site repository construction. No excavated waste would be hauled through the community. Lower haul miles through the community would also result in fewer traffic accidents.

Alternative 4 (haul routes through the community) has the highest impact on traffic, truck and dust emissions, and possibility of traffic accidents. Therefore, Alternative 4 is rated **Poor** to **Very Poor** because of the longer roundtrip distance to the disposal facilities.

The Alternative 1 is rated **Very Good** as no removal activities would be conducted to impact the community.

Protection of Workers during Removal Action

Worker protection primarily involves radiation exposure, dust inhalation hazards, physical injury, and traffic accidents. All action alternatives involve the same degree of excavation work; therefore, all action alternatives have equal amounts of potential radiation exposure, potential dust inhalation hazards, and potential for injury to workers. However, Alternatives 2 and 3 involve construction of a repository, which introduces an additional level of threat to workers because of additional handling activities and duration of exposure during consolidation and capping.

The rate of traffic accidents is proportional to the amount of hauling for that alternative. For the action alternatives, the total haul distance on all roadways for Alternative 2 is approximately 1 mile, with an accident risk of 0.01, Alternative 3 is 0 miles (on site), Alternative 4 is approximately 400 miles (round trip, disposal at the closer White Mesa Mill) with an accident risk of 0.26, or approximately 1,200 miles (round trip, disposal at the more distant Clean Harbors hazardous waste facility) with an accident risk of 0.77.

Even though Alternatives 2 and 3 pose an additional hazard associated with additional handling and exposure to waste during consolidation and capping, the long haul distances for off-Navajo Nation disposal pose the greatest accident threat to truck drivers. Therefore, Alternative 4 with the shorter haul distance (White Mesa Mill) is rated **Poor**, the more distant facility (Clean Harbors) is rated **Very Poor**. Alternatives 2 and 3 are rated **Good** based on the small footprints and short haul

distances. The Alternative 1 is rated **Very Good** as no removal activities would be conducted to impact workers.

Environmental Impacts

Shorter haul distances and construction durations minimize the potential for construction-related environmental impacts to occur both on public roads and off road and in the construction areas that would require mitigation. These impacts may include residual track-in and track-out effects of soil and mud, noise, nuisance, soil spills during waste hauling, sedimentation of local drainages, and harmful emissions. In addition, construction of a repository increases the amount of construction while off-site disposal increases fuel consumption and greenhouse gas emissions. Site visits and construction for long-term O&M (1,000 years) are expected to have an impact on alternative environmental footprints.

Summary. Alternatives 2 and 3 rated **Good** because the short haul distances require less energy and produce a smaller greenhouse gas footprint than off-Navajo Nation hauling under Alternative 4. In addition, Alternative 2 and 3 could limit future land uses because of the need to protect repository caps. Alternative 4 is rated **Very Poor** because of the large energy requirements and greenhouse gases produced by 43,000 truckloads of waste. Alternative 1 is rated **Very Good** as no removal action would be performed.

Time Until Removal Action Objectives Are Achieved

A summary of the construction completion time for each alternative are presented below. All action alternatives could be completed between 2 and 17 years.

Alternative	Construction Completion Time
1	0 years
2A	2 years, 1 month
2B	2 years, 1 month
3A	2 years, 6 months
3B	2 years, 6 months
4A	8 years, 9 months
4B	17 years, 2 months

5.2.1.4 Long-Term Effectiveness and Permanence (after Removal Action)

For all action alternatives, waste removal or containment from source areas would reduce the magnitude of residual risk to background levels for radionuclides. Noncancer hazards would be removed, and risk to ecological receptors would be reduced to levels below known effects concentrations and background levels. None of the alternatives reduce the toxicity, mobility, or volume through treatment.

Alternative 4 is rated **Very Good** as sources of risk at the site as waste would be removed and disposed of off the Navajo Nation. However, the off-Navajo Nation milling process increases the toxicity of the waste at the tailings disposal facility. The cap and liner at the tailings disposal facility would eliminate exposure pathways. Alternative 4 would also allow for unrestricted future use of the entire site. Removing waste from the Navajo Nation eliminates the long-term surveillance requirements associated with a repository under Alternatives 2 and 3.

Alternatives 2 and 3 would consolidate all waste in a repository. Permanence of risk reduction would rely on the repository design standards to minimize long-term maintenance, but long-term surveillance of the repository would still be required. Alternatives 2 and 3 are both rated **Good**. Although the on-site repositories (Alternatives 2 and 3) are expected to be fully protective in both the short and long term, the ET cap will require a long-term maintenance and monitoring commitment. Replacement of repository components would not be required because their lifespan is indefinite, especially under a monitoring and maintenance regime.

Alternative 1 is rated **Very Poor** because no removal action would be performed. Human health risk may be partially reduced through increased awareness of risks, but no reduction in risk to the ecosystem would occur. Uncontrolled and untreated waste would remain and continue to be accessible by humans and animals and subject to potential migration to uncontaminated or less contaminated areas.

5.2.2 Implementability

Implementability comprises two criteria: (1) technical feasibility and availability of services and materials, and (2) administrative feasibility. Overall implementability is rated **Very Good** for Alternative 1, **Good** for Alternative 2, **Good** for Alternative 3, and **Good** for Alternative 4.

5.2.2.1 Technical Feasibility and Availability of Services and Materials

Action alternatives consist mainly of simple earthwork and material hauling. The alternatives are technically feasible with labor available through the local and regional market and equipment and materials located 1.5 to 2 hours away.

The action alternatives would be completed as a single phase, and no future remedial actions are anticipated. Short-term monitoring of site restoration features will occur under all action alternatives while long-term monitoring and maintenance, particularly inspection and repair of erosional features and controls and revegetation, would be required for on-site repositories. Experienced contractors, construction equipment, and materials are available with the region.

Among the action alternatives, Alternative 4 is the most technically feasible to implement as all waste is removed from the Quivira mines. Design methods, construction practices, and engineering requirements are well documented and understood. However, the reliance on the disposal capacity of contracted services brings uncertainty to the availability of off-Navajo Nation disposal capacity. Therefore, Alternative 4 is rated **Good**.

Alternatives 2 and 3 are both technically feasible as waste is consolidated in an on-site repository. Design methods, construction practices, and engineering requirements are well documented and understood. Because all waste under the Alternatives 2 and 3 would be disposed of on site, no

reliance on the treatment, storage, or disposal capacity of contracted services would be required. Alternatives 2 and 3 are rated **Good**.

Alternative 1 is rated **Very Good** as it is readily implementable and no construction is involved. Alternative 1 would not impact the ability to conduct removal or remedial actions in the future. No services or materials would be needed because no removal action would be performed.

5.2.2.2 Administrative Feasibility

Administratively, Alternative 4 is rated **Good** as it requires the least amount of design, permitting, and approvals from and coordination with agencies as no on-site repository would be involved. Post-remedy inspections, reviews, and land use controls would be limited in comparison to on-site repository construction. However, limitations and delays on waste acceptance at off-Navajo Nation facilities are possible because of the volume of waste or disposal facility permit limitations.

The on-site repositories under Alternative 2 and 3 are both located away from the community. Alternative 2 is rated **Good** as less design, permitting, approvals, and coordination with agencies is required for one on-site repository in comparison to Alternative 3, with two separate on-site repositories. Alternative 3 is rated **Average** based on the additional requirements for the second repository.

Alternative 1 is rated **Very Good** as taking no action is feasible. However, future removal or remedial actions could still occur under CERCLA or through other actions of the Navajo Nation or Tronox.

5.2.2.3 Tribal and Supporting Agency Acceptance

Acceptance by the Navajo Nation and supporting agencies is an additional criterion that will be addressed in the final AAM report and action memorandum after stakeholder comments have been received on this AAM.

5.2.2.4 Community Acceptance

Acceptance by the Coyote Canyon, Nahodishgish, Standing Rock, Pinedale, and Church Rock Chapter communities is an additional criterion that will be addressed in the final AAM report and action memorandum after public comments have been received on this AAM.

5.2.3 Projected Costs

A summary of the cost for each alternative is presented below. Alternative costs are presented as a rating (comparing each alternative to the others) and as the total estimated cost based on 2021 price evaluations for each alternative.

Alternative	Cost Rating	Total Estimated Cost (2021 million dollars)
1	Very Good	$0
2	Good	$41.1 M
3	Average	$46.6 M
4A	Poor	$276.3 M
4B	Very Poor	$550.6 M

Note:
Higher cost alternatives rate lower in cost ratings, which is consistent with the rating scheme where low = less desirable.

Present values, including O&M costs, for each action alternative using a baseline 10-year project duration for site restoration and 1,000-year (required under UMTRCA 40 CFR § 192[d] Part A) project duration for on-site consolidation and capping (Alternatives 2 and 3) at a 3.5 percent discount rate (30-year rolling average) (OMB 2020) are summarized below.

Alternative	Capital Cost	O&M Present Value (10 years) 3.5% discount rate	O&M Present Value (1,000 years) 3.5% discount rate
1	$0	$0	$0
2A	$41,101,000	$524,840	$1,399,687
2B	$41,845,000	$524,840	$1,399,687
3A	$46,557,000	$403,370	$1,816,993
3B	$47,413,000	$403,370	$1,816,993
4A	$276,343,000	$920,336	Not Applicable
4B	$550,579,000	$920,336	Not Applicable

Note:
O&M Operation and maintenance

Alternative 1 is the least expensive because no construction and O&M costs are incurred and is rated **Very Good**. Alternative 2 ($41 million, rated **Good**) is $5 million less than Alternative 3 ($46 million, rated **Average**) and both have comparable O&M costs**.** Alternatives 4A and 4B are rated **Poor** and **Very Poor**, respectively since their costs are an order of magnitude higher than Alternatives 2 and 3.

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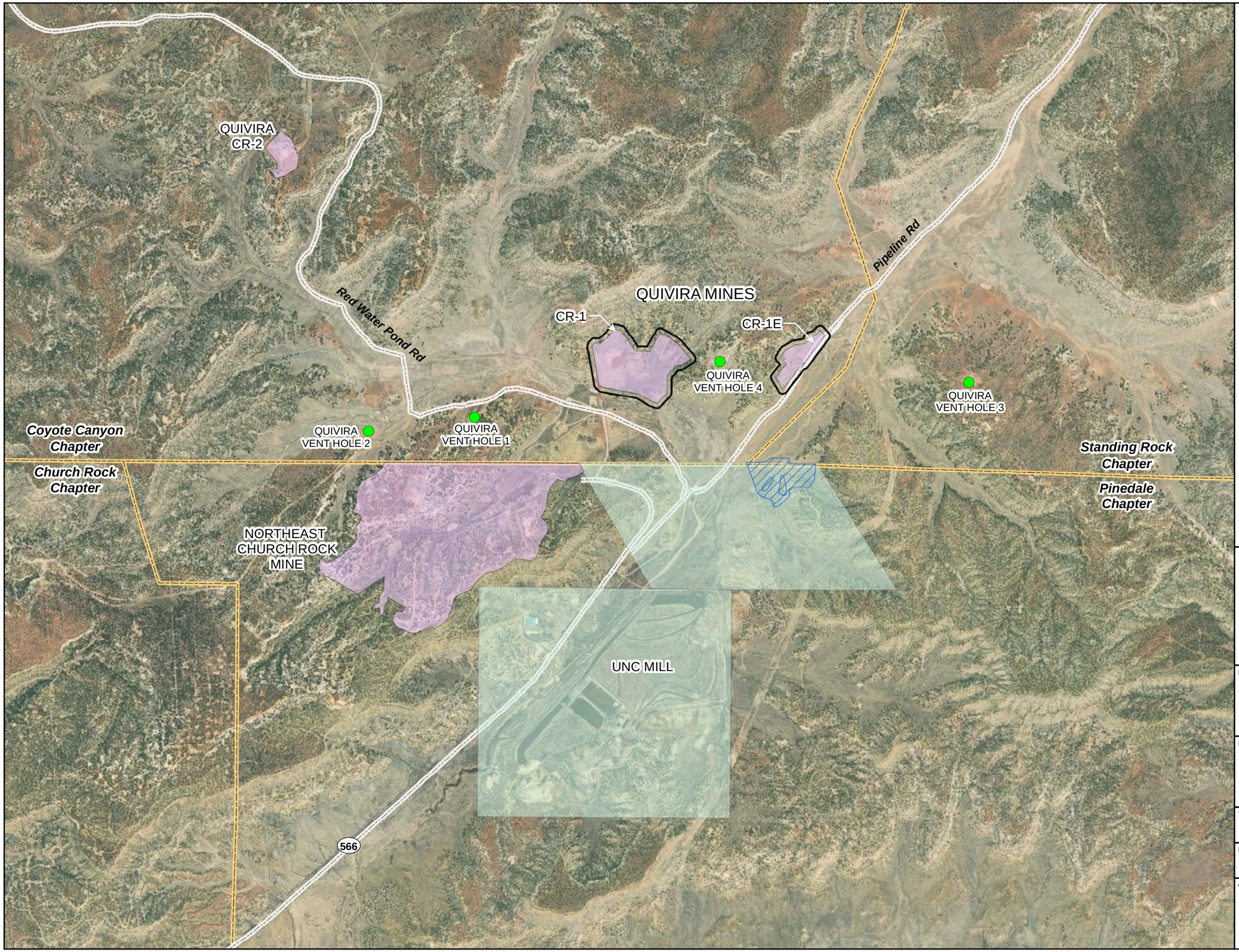
FIGURES



Mine Lease Boundary
UNC Mill Boundary
Navajo Nation Chapter Boundary
Kerr McGee Ponds
Access Route
Mine Vent Hole

1 inch = 2,000 feet

1:24,000

N
W E
S

2,000 1,000 0 2,000 Feet

QUIVIRA MINES
SITE LOCATION MAP

Prepared For: U.S. EPA Region 9

Prepared By:

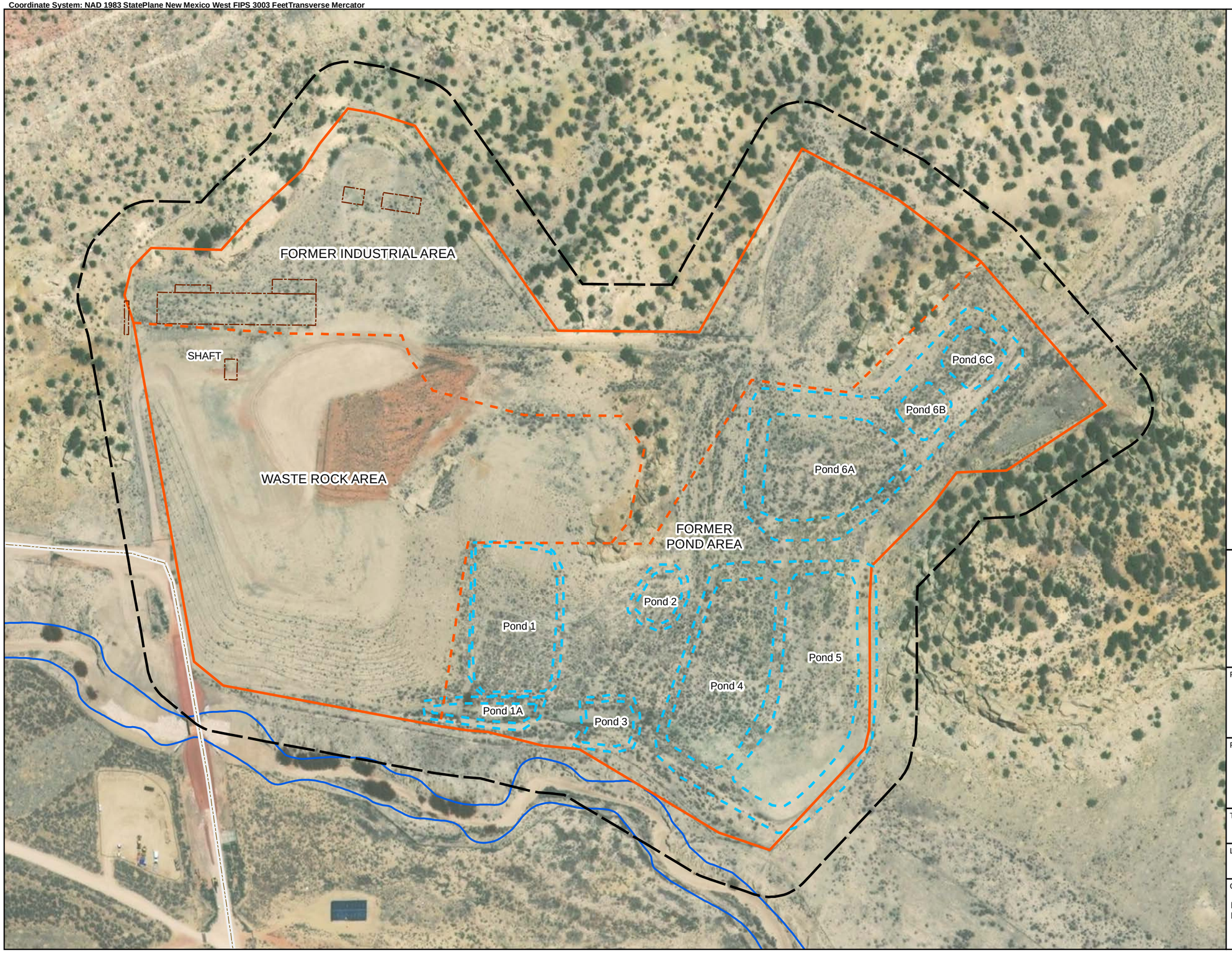
TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

Task Order No.:	Contract No.:
0003	EP-S9-17-03
Location:	**Date:**
NAVAJO NATION	9/29/2021

Coordinate System:
NAD 1983 State Plane New Mexico West
FIPS 3003 Feet Transverse Mercator

Figure No.:
1

Coordinate System: NAD 1983 StatePlane New Mexico West FIPS 3003 FeetTransverse Mercator



CR-1 Lease Boundary
CR-1 100-ft Step Out Boundary
CR1_Former_Buildings
Former Pond
Sub Area Limit
Red Water Pond Road
Unnamed Arroyo #2

1 in = 200 feet

1:2,400

N
W E
S

200 100 0 200 Feet

QUIVIRA CHURCH ROCK 1 (CR-1)
SITE FEATURES MAP

Prepared For: U.S. EPA Region 9

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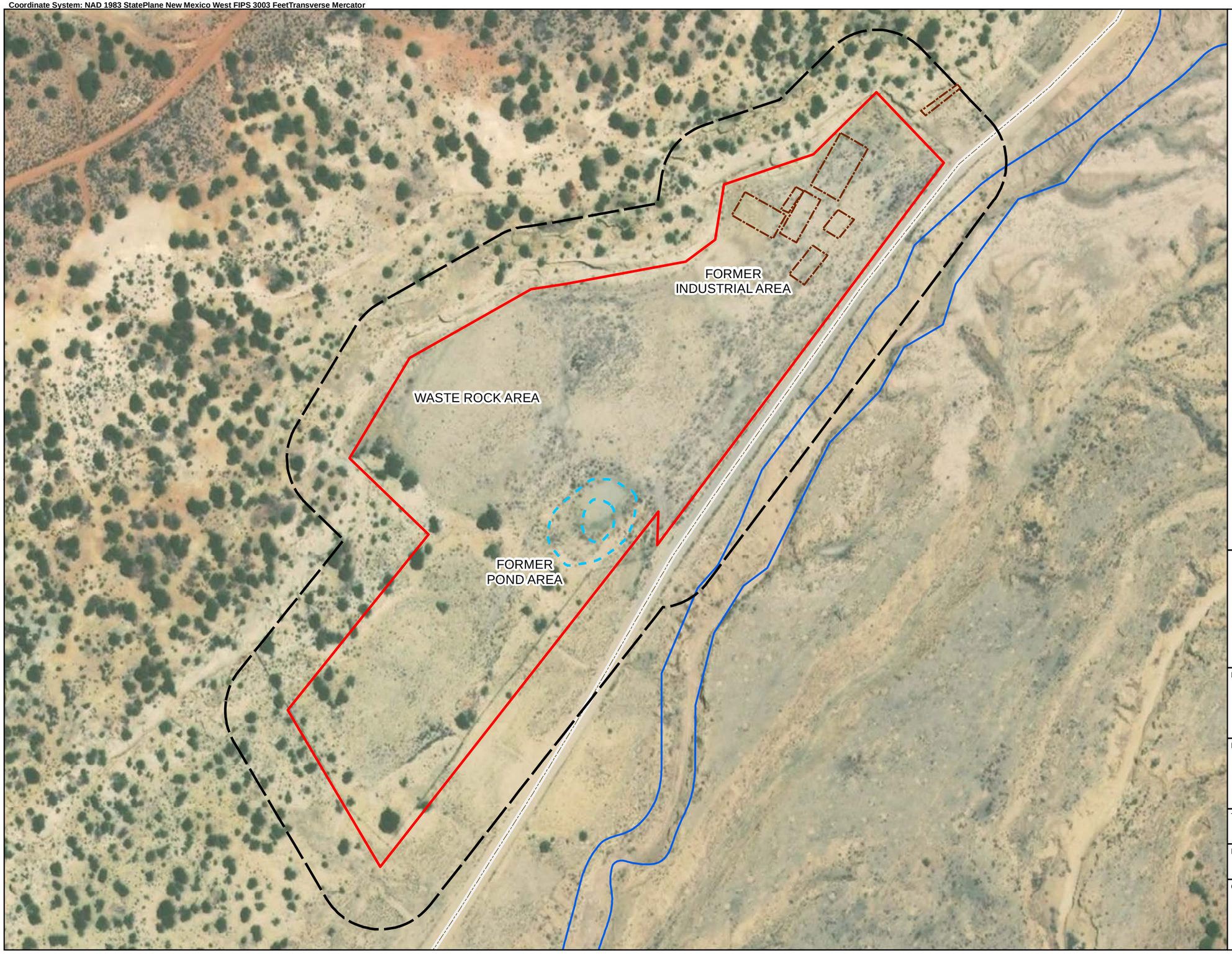
Task Order No.:	Contract No.:
TO0003	EP-S9-17-03
Location: COYOTE CANYON CHAPTER NAVAJO NATION	Date: 10/19/2020
Coordinate System: NAD 1983 State Plane New Mexico West FIPS 3003 Feet Transverse Mercator	Figure No.: 2

\\TT5273FS1.TT.LOCAL\PROJECTS\EPA_RAES-NAVAJO NATION_100G5440\TASK ORDERS\TO-003_QUIVIRA EE-CA\WORKING FILES\GIS\MXD\REVISED_EECAIUPDATED2020\0Z_CR1_SITE_FEATURES.MXD 10/19/20

Coordinate System: NAD 1983 StatePlane New Mexico West FIPS 3003 FeetTransverse Mercator



CR-1E Lease Boundary
CR-1E 100-ft Stepout Boundary
CR1E_Former_Buildings
CR1E_Former_Pond
Pipeline Canyon Road
Arroyo_Pipeline

1 in = 150 feet

1:1,800

N
W E
S

150 75 0 150 Feet

QUIVIRA CHURCH ROCK 1 **EAST**
(CR-1**E**) SITE FEATURES MAP

Prepared For: U.S. EPA Region 9

Prepared By:
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Task Order No.:	Contract No.:
TO0003	EP-S9-17-03
Location: STANDING ROCK CHAPTER NAVAJO NATION	Date: 12/19/2019
Coordinate System: NAD 1983 State Plane New Mexico West FIPS 3003 Feet Transverse Mercator	Figure No.: 3

C:\USERS\JIM.HERNING\DOCUMENTS\EMIFIELD DEPLOYMENT\RAES_GIS\TO-003\MXD\REVISED_EECA\03_CR1E_SITE_FEATURES.MXD 11/06/19

Kerr McGee Ponds
UNC Mill Boundary
TENORM Boundary

1 inch = 200 feet

1:2,400

N
W E
S

200 100 0 200 Feet

KERR MCGEE PONDS SITE LOCATION

Prepared For: U.S. EPA Region 9

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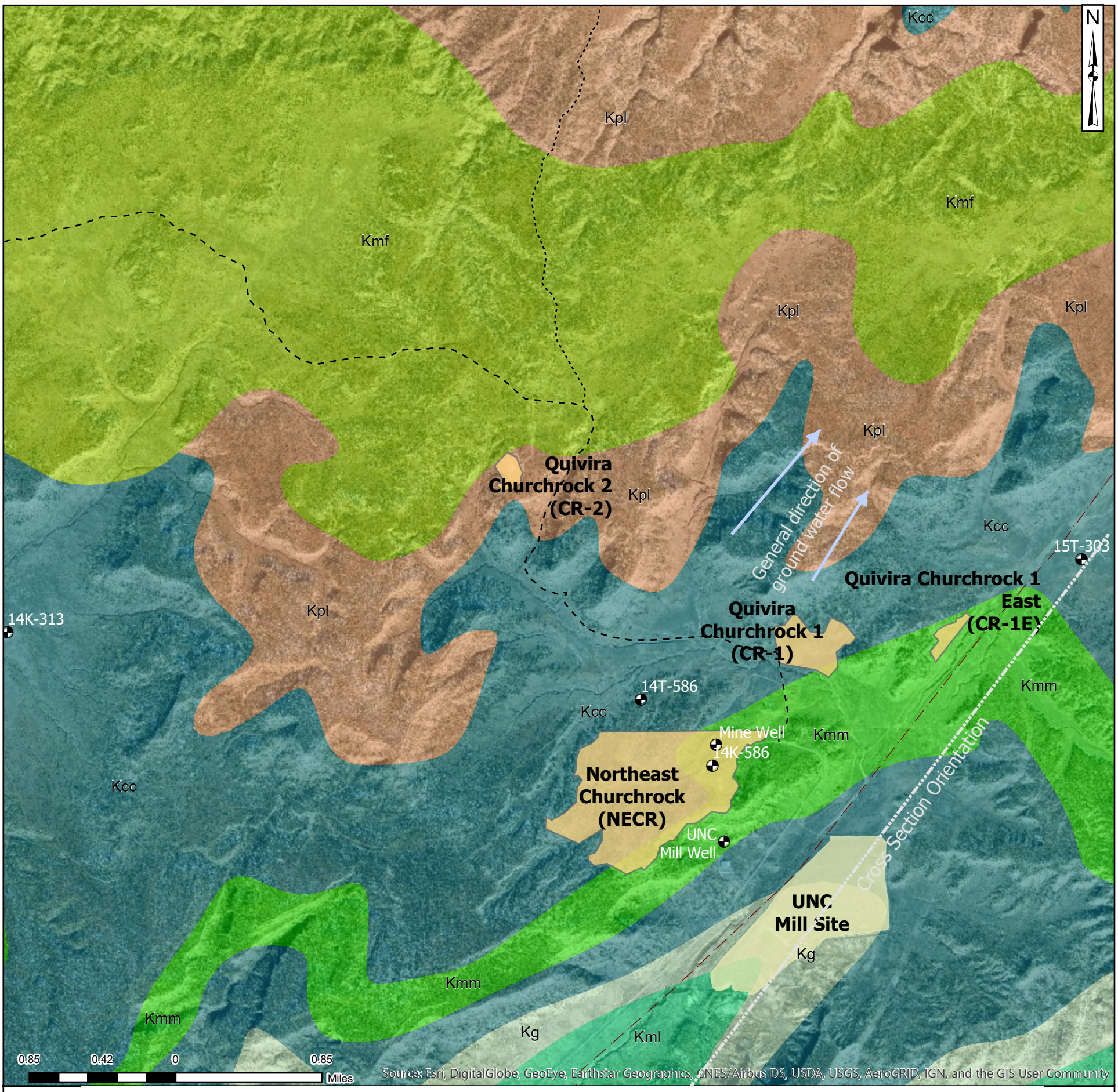
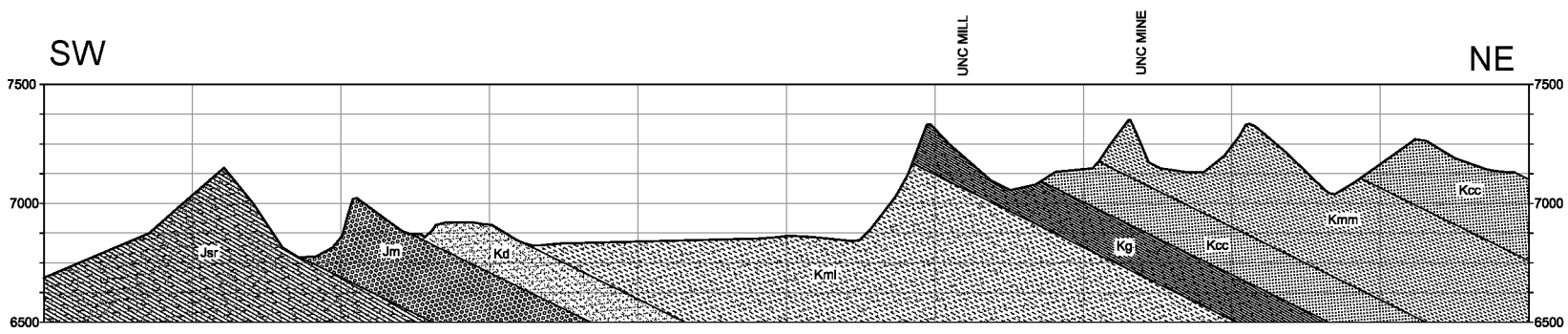
Task Order No.:	Contract No.:
0003	EP-S9-17-03
Location:	**Date:**
NAVAJO NATION	9/29/2021

Coordinate System:	Figure No.:
NAD 1983 State Plane New Mexico West FIPS 3003 Feet Transverse Mercator	4





LEGEND:

- Trc - CHINLE GROUP
- Jsr - SAN RAFAEL FROUP (ENTRADA; TODILTO; SUMERVILLE)
- Jm - MORRISON GROUP
- Kd - DAKOTA
- Kml - MANCOS SHALE
- Kg - GULLOP SANDSTONE
- Kcc - CREVASSE CANYON
- Kmm - MULATTO TONGUE OF MANKOS

CROSS SECTION VIEW WITH EXAGGERATED VERTICAL SCALE

HORIZONTAL SCALE: 1"=5000'
VERTICAL SCALE: 1"=500'

0' 1000'

Source: Engineering/Remediation Resources Group, Inc. (ERRG), 2011. "Regional Groundwater Assessment of Impacts from Historic Releases of the NECR Mine and UNC Mill Facilities, Navajo Nation." Prepared by USEPA, Region 9. September.

- Well
- Red Water Pond Road
- Site Access Road
- Pipeline Arroyo
- Mine
- UNC Mill
- Kcc Crevasse Canyon Formation
- Kg Gallup Sandstone Formation
- Kmf Meneffee Formation
- Kml Mancos Shale
- Kmm Mulatto Tongue of Mancos Shale
- Kpl Point Lookout Sandstone

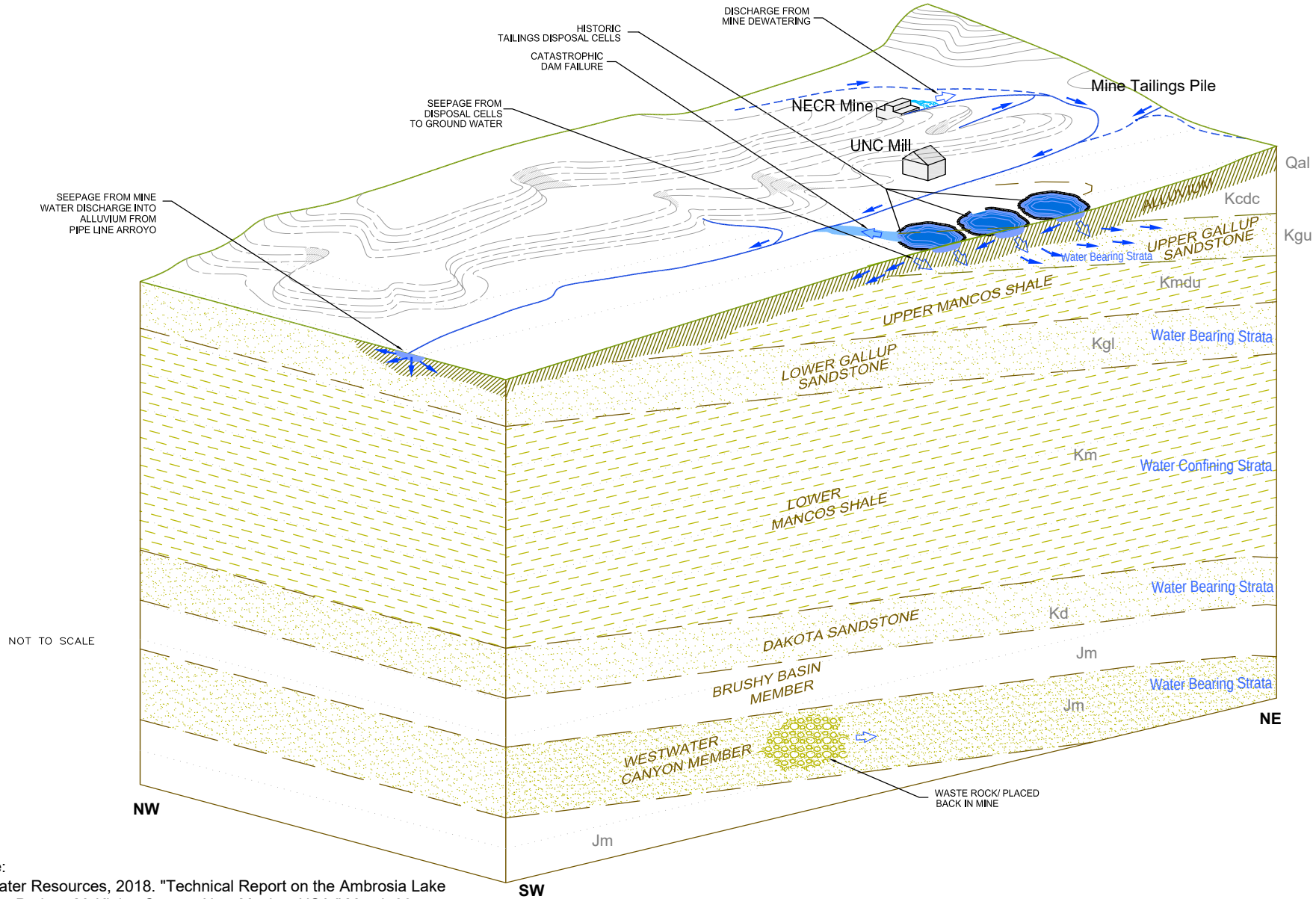
Prepared for: U.S. EPA Region 9

Prepared By: TETRA TECH

LOCAL GEOLOGY AND MINE BOUNDARIES

Task Order No.:	Contract No.:	Figure No.:
TO0003	EP-S9-17-03	5A
Location: QUIVIRA TRONOX MINES NAVAJO NATION	Date: 4/5/2019	

C:\USERS\KARINA.REDDING\DOCUMENTS\ARCGIS\PROJECTS\NEW MEXICO\NEW MEXICO.APRX



Source:
Westwater Resources, 2018. "Technical Report on the Ambrosia Lake Uranium Project, McKinley County, New Mexico, USA." March 30.

Legend

- Mine
- Tributary Alignment
- Ephemeral Stream
- Geologic Contact
- Water Flow Direction
- Historic Release

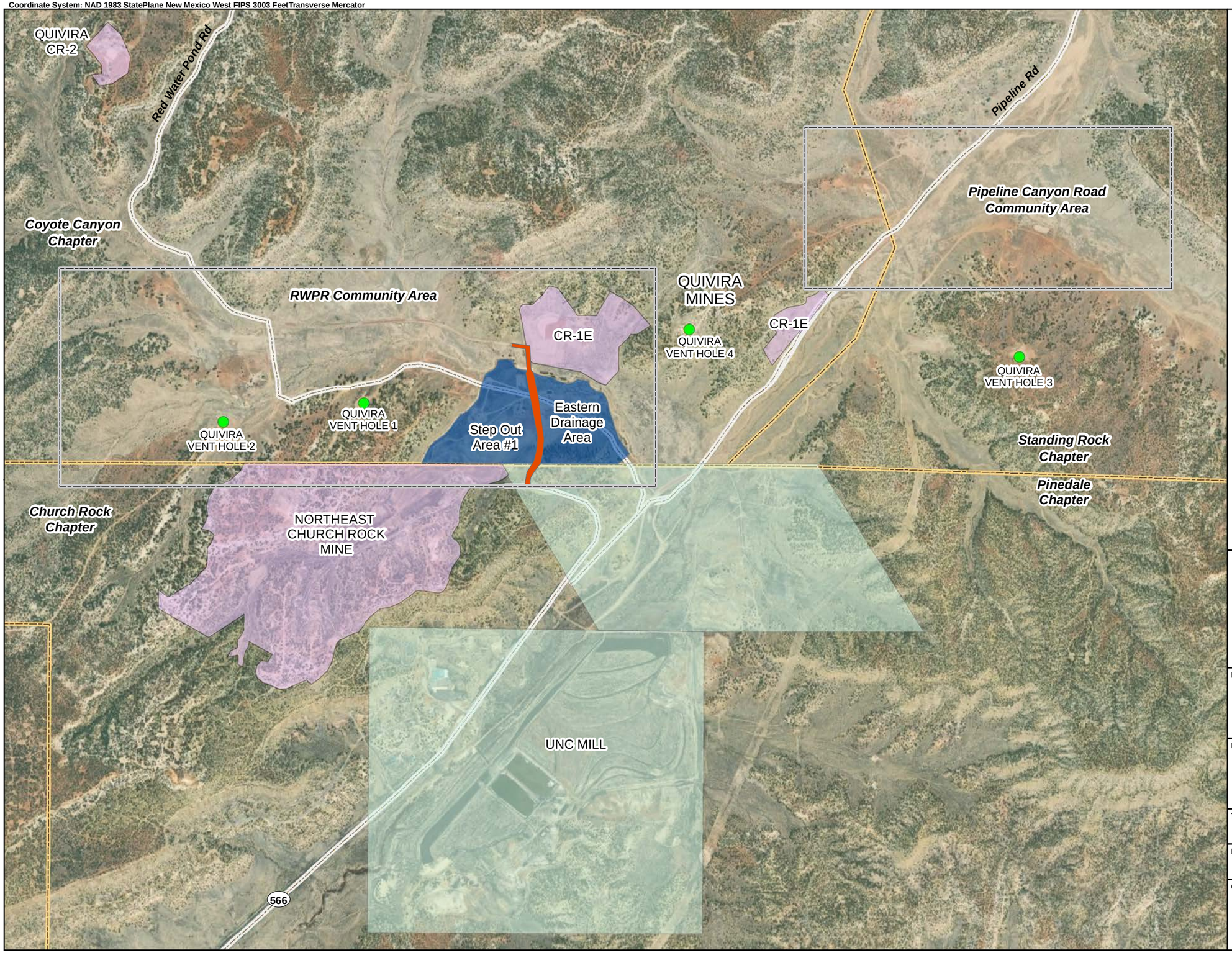
Prepared for:

Prepared By: TETRA TECH

CONCEPTUAL DRAWING OF HISTORIC RELEASES AND WATER FLOW

Task Order No.:	Contract No.:	Figure No.:
TO0003	EP-S9-17-03	5B
Location: NAVAJO NATION	Date: 4/5/2019	

Coordinate System: NAD 1983 StatePlane New Mexico West FIPS 3003 FeetTransverse Mercator



- Mine Lease Boundary
- UNC Mill Boundary
- RWPR_Removal
- Fenced_Stepout
- Community_Area
- Navajo Nation Chapter Boundary
- Access Route
- Mine Vent Hole

1 in = 1,500 feet

1:18,000

N
W E
S

1,500 750 0 1,500 Feet

QUIVIRA MINES VICINITY AND PRIOR REMOVAL ACTIONS

Prepared For: U.S. EPA Region 9

Prepared By:

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Oakland, CA 94612

Task Order No.:	Contract No.:
TO0003	EP-S9-17-03
Location: NAVAJO NATION	Date: 10/19/2020
Coordinate System: NAD 1983 State Plane New Mexico West FIPS 3003 Feet Transverse Mercator	Figure No.: 6

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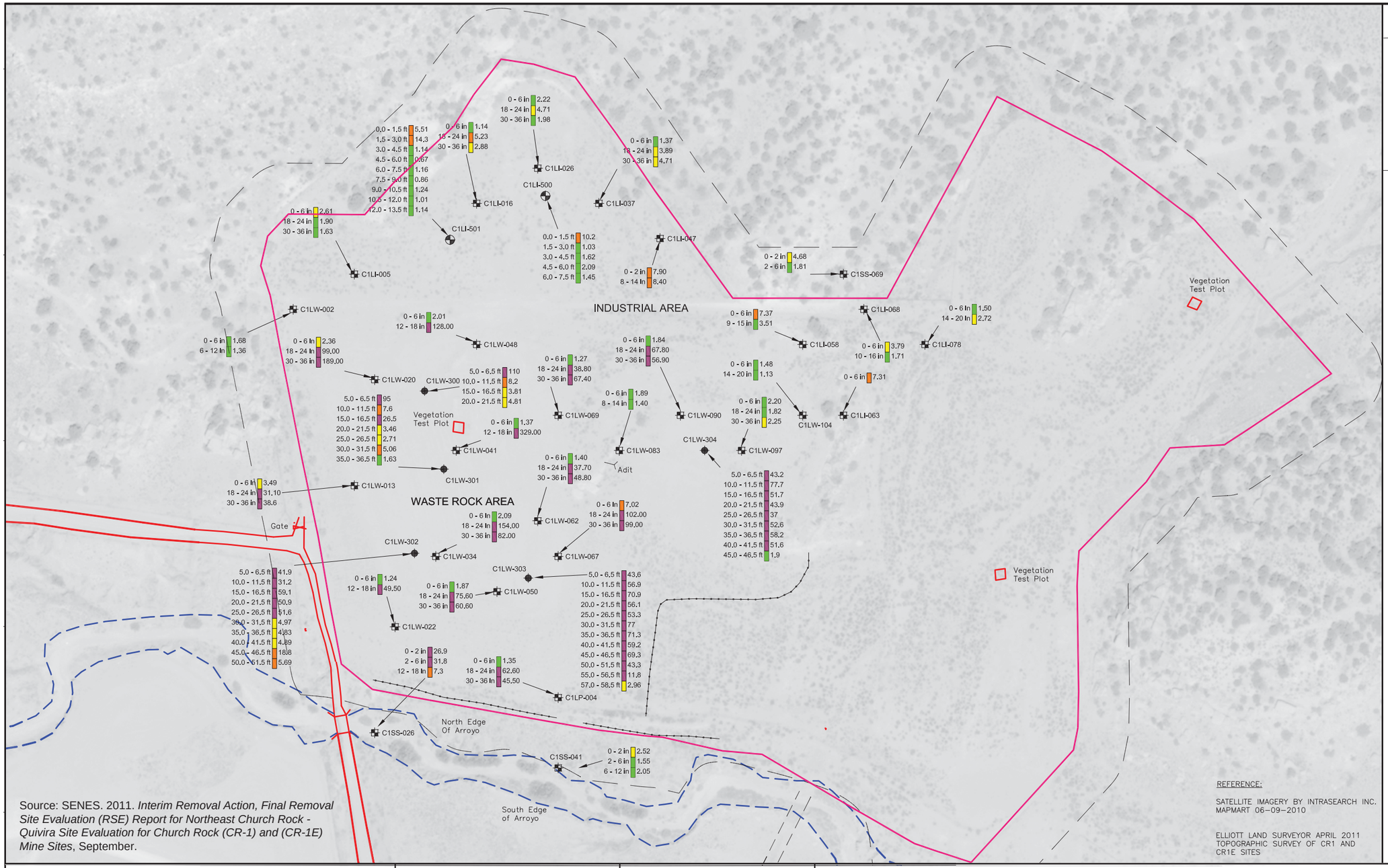
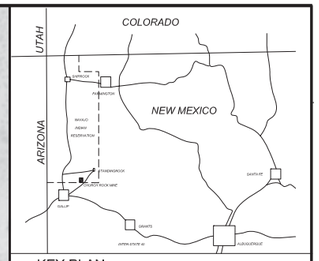


Source: SENES. 2011. *Interim Removal Action, Final Removal Site Evaluation (RSE) Report for Northeast Church Rock - Quivira Site Evaluation for Church Rock (CR-1) and (CR-1E) Mine Sites*, September.



KEY PLAN

LEGEND:

C1LW-301	SUBSURFACE BOREHOLE LOCATIONS (WASTE ROCK STOCKPILE AREA)
C1LI-501	SUBSURFACE BOREHOLE LOCATIONS (FORMER INDUSTRIAL AREA)
C1LP-404	SUBSURFACE BOREHOLE LOCATIONS (FORMER POND AREA)
C1LW–022	SHALLOW SURFACE SAMPLE LOCATIONS (WASTE ROCK STOCKPILE AREA)
C1LI–016	SHALLOW SURFACE SAMPLE LOCATIONS (FORMER INDUSTRIAL AREA)
C1LP–070	SHALLOW SURFACE SAMPLE LOCATIONS (FORMER POND AREA)
C1SS–082	SHALLOW SURFACE SAMPLE LOCATIONS ON STEP OUT AREA
	LEASE BOUNDARY
	100 ft STEP OUT BOUNDARY

Borehole Legend

Depth Range (inch/feet) | Lab Result (pCi/g)

Illustrative Data Ranges

MAUVE	Lab Result above 25.0 pCi/g
ORANGE	Lab Result above 5.0 to 25.0 pCi/g
YELLOW	Lab Result Between 2.24 and 5.0 pCi/g
GREEN	Lab Result Below 2.24 pCi/g

REFERENCE:

SATELLITE IMAGERY BY INTRASEARCH INC. MAPMART 06–09–2010

ELLIOTT LAND SURVEYOR APRIL 2011 TOPOGRAPHIC SURVEY OF CR1 AND CR1E SITES

N

0 600

Scale in Feet

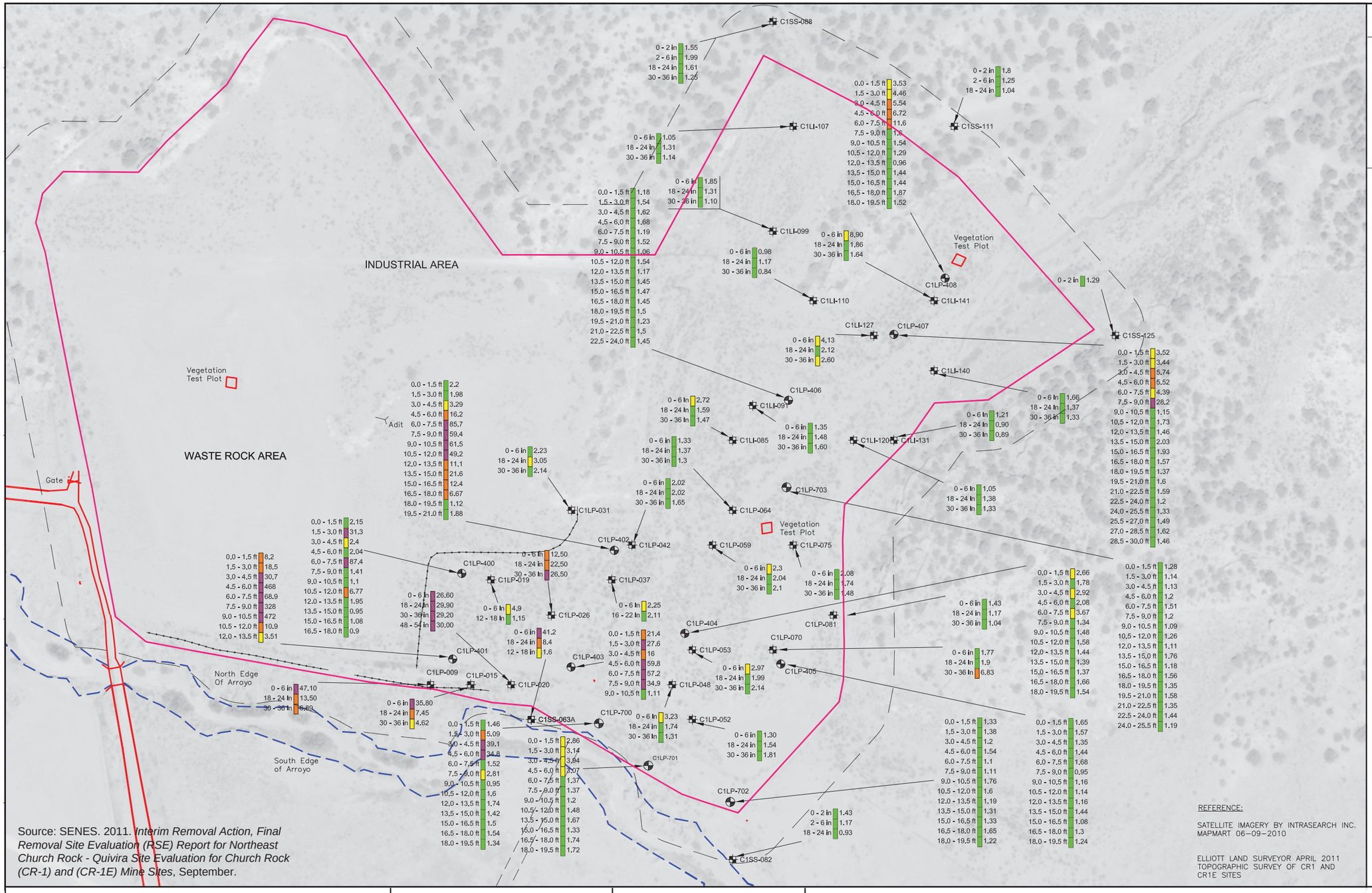
PREPARED BY:
Region 9, START
Weston Solutions, Inc.
2300 Clayton Rd, Ste
900 Concord, CA 94520

PREPARED FOR:
USEPA Region 9
Pacific
Southwest

FIGURE 7
QUIVIRA CR-1 WASTE ROCK/INDUSTRIAL AREA SAMPLE RESULTS
QUIVIRA TRONOX MINE SITE EE/CA
Navajo Nation, NM

Contract: EP-S5-13-02; **TDD**: 0015/1302-T15-R9-14-12-0001

DCN: 0036-08-AAEU



Source: SENES. 2011. *Interim Removal Action, Final Removal Site Evaluation (RSE) Report for Northeast Church Rock - Quivira Site Evaluation for Church Rock (CR-1) and (CR-1E) Mine Sites*, September.

N

0 600

Scale in Feet

PREPARED BY:
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2300 Clayton Rd, Ste 900
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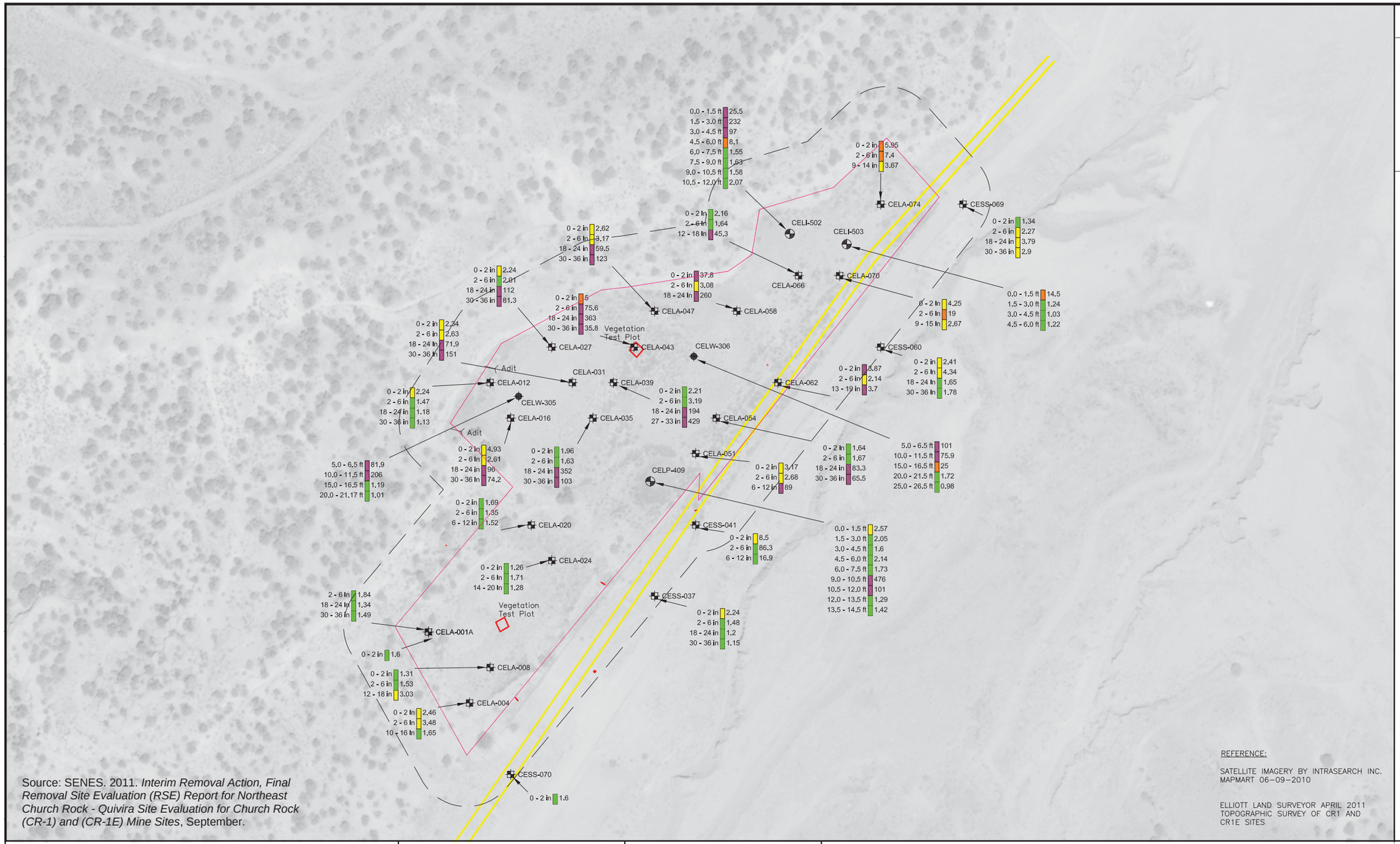
PREPARED FOR:
USEPA Region 9
Pacific
Southwest

FIGURE 8
QUIVIRA CR-1 FORMER POND AREA SAMPLE RESULTS
QUIVIRA TRONOX MINE SITE EE/CA
Navajo Nation, NM

Contract: EP-S5-13-02; **TDD:** 0015/1302-T15-R9-14-12-0001

DCN: 0036-08-AAEU



Source: SENES. 2011. *Interim Removal Action, Final Removal Site Evaluation (RSE) Report for Northeast Church Rock - Quivira Site Evaluation for Church Rock (CR-1) and (CR-1E) Mine Sites*, September.

N

0 400

Scale in Feet

PREPARED BY:
Region 9, START
Weston Solutions, Inc.
2300 Clayton Rd, Ste 900
Concord, CA 94520

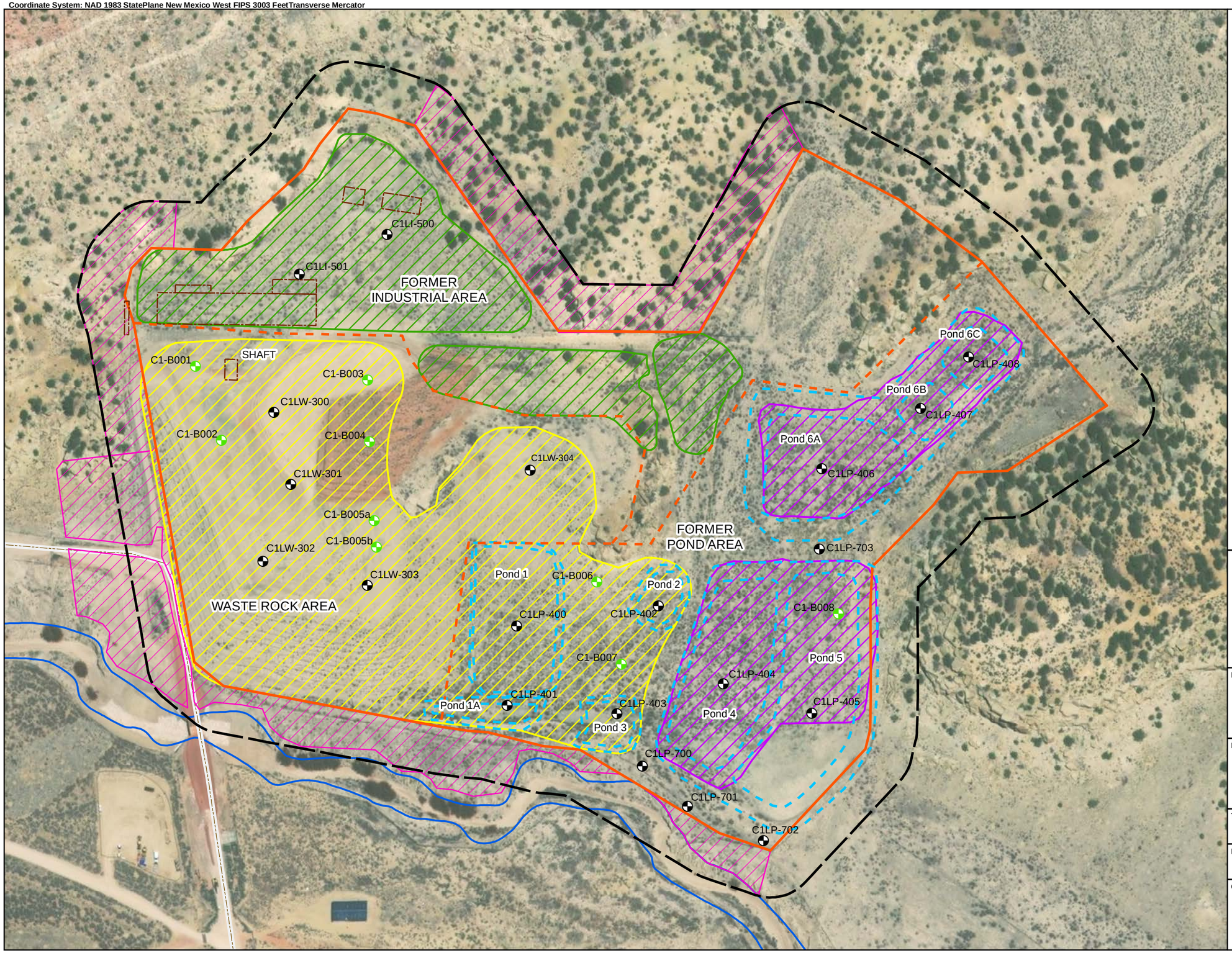
PREPARED FOR:
USEPA Region 9
Pacific
Southwest

FIGURE 9
QUIVIRA CR-1E SAMPLE RESULTS
QUIVIRA TRONOX MINE SITE EE/CA
Navajo Nation, NM

Contract: EP-S5-13-02; **TDD:** 0015/1302-T15-R9-14-12-0001

DCN: 0036-08-AAEU

Coordinate System: NAD 1983 StatePlane New Mexico West FIPS 3003 FeetTransverse Mercator



- CR-1 Lease Boundary
- CR-1 100-ft Step Out Boundary
- Contaminated Waste Rock/Ponds 1-3 Area
- Contaminated Former Ponds 4-6 Area
- Contaminated Former Industrial Area
- Contaminated Step-Out Area
- CR1_Former_Buildings
- Former Pond
- Sub Area Limit
- Red Water Pond Road
- Unnamed Arroyo #2
- Borehole Location (SENES, 2011)
- Borehole Location (Weston, 2015)

1 in = 200 feet

1:2,400

N
W E
S

200 100 0 200 Feet

QUIVIRA (CR-1)
CONTAMINATED AREAS MAP

Prepared For: U.S. EPA Region 9

Prepared By:

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Task Order No.:	Contract No.:
TO0003	EP-S9-17-03
Location: COYOTE CANYON CHAPTER NAVAJO NATION	Date: 10/19/2020
Coordinate System: NAD 1983 State Plane New Mexico West FIPS 3003 Feet Transverse Mercator	Figure No.: 10

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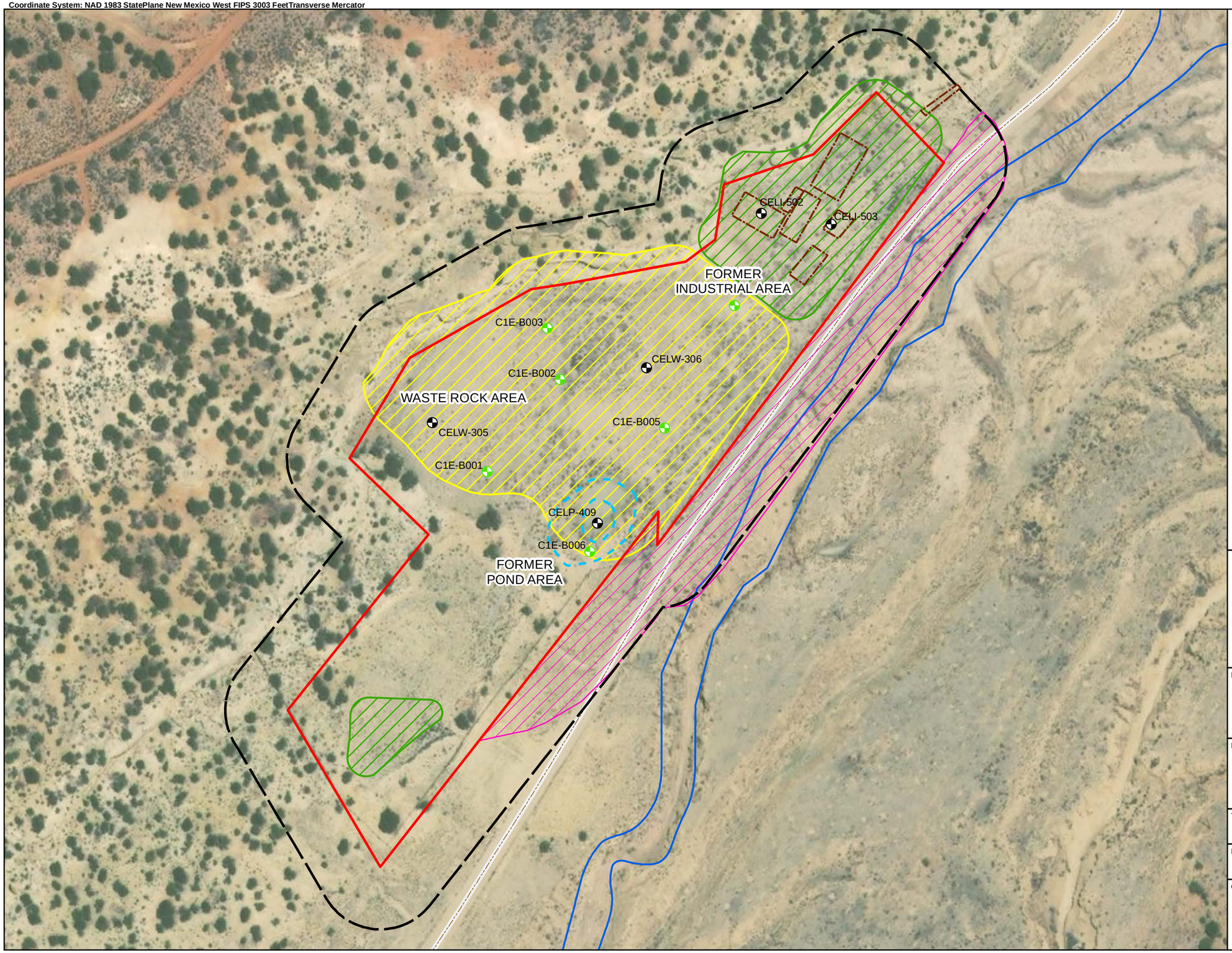
Coordinate System: NAD 1983 StatePlane New Mexico West FIPS 3003 FeetTransverse Mercator



- CR-1E Lease Boundary
- CR-1E 100-ft Stepout Boundary
- Contaminated Waste Rock/Pond Area
- Contaminated Former Industrial Area
- Contaminated Setp-Out Area
- CR1E_Former_Buildings
- CR1E_Former_Pond
- Pipeline Canyon Road
- Arroyo_Pipeline
- Borehole Location (SENES, 2011)
- Borehole Location (Weston, 2015)

1 in = 150 feet

1:1,800

N W E S

150 75 0 150 Feet

QUIVIRA (CR-1E)
CONTAMINATED AREAS MAP

Prepared For: U.S. EPA Region 9

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Task Order No.:	Contract No.:
TO0003	EP-S9-17-03
Location: STANDING ROCK CHAPTER NAVAJO NATION	Date: 10/19/2020
Coordinate System: NAD 1983 State Plane New Mexico West FIPS 3003 Feet Transverse Mercator	Figure No.: 11

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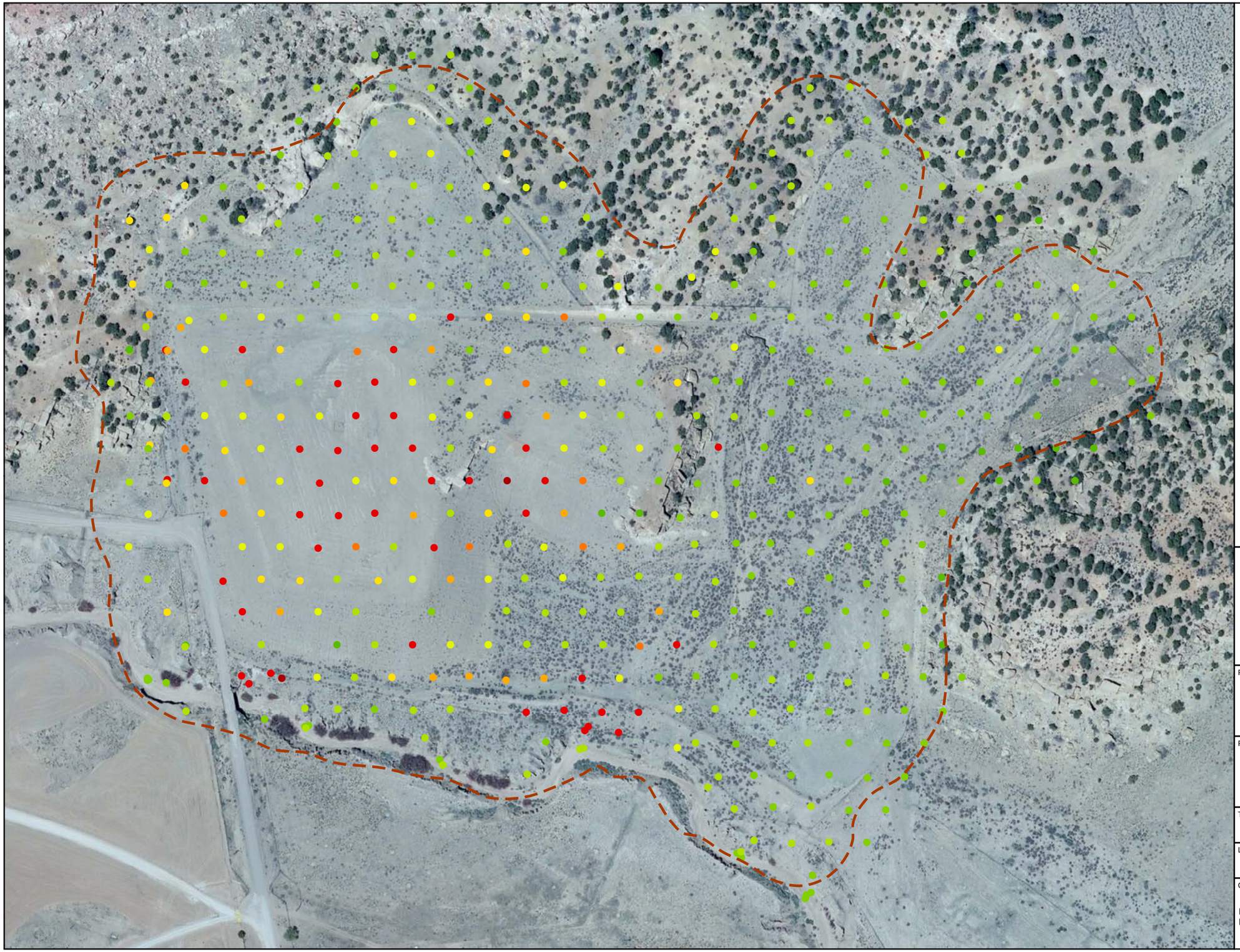

TENORM_Boundary

Gamma

- < 3,000 cpm
- 3,000 - 4,000 cpm
- 4,000 - 5,000 cpm
- 5,000 - 6,000 cpm
- 6,000 - 7,000 cpm
- 7,000 - 8,000 cpm
- 8,000 - 9,000 cpm
- 9,000 - 10,000 cpm
- 10,000 - 20,000 cpm
- > 20,000

1 inch = 200 feet

1:2,400

N W E S

200 100 0 200 Feet

CR1 STATIC GAMMA SCAN

Prepared For: U.S. EPA Region 9

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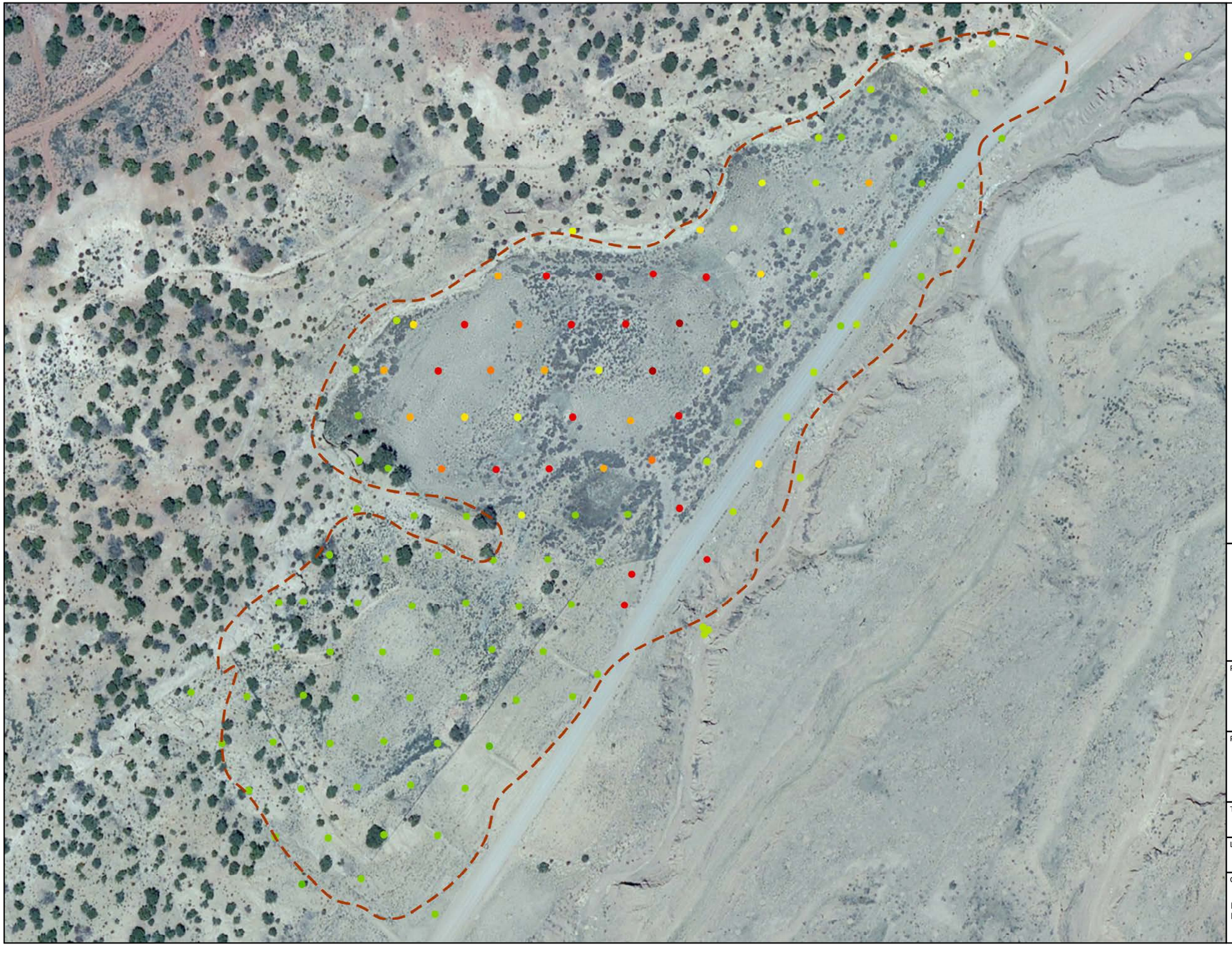
Task Order No.:	Contract No.:
0003	EP-S9-17-03
Location:	**Date:**
NAVAJO NATION	9/27/2021

Coordinate System:	Figure No.:
NAD 1983 State Plane New Mexico West FIPS 3003 Feet Transverse Mercator	**12**



TENORM Boundary

Gamma

- < 3,000
- 3,000 - 4,000 cpm
- 4,000 - 5,000 cpm
- 5,000 - 6,000 cpm
- 6,000 - 7,000 cpm
- 7,000 - 8,000 cpm
- 8,000 - 9,000 cpm
- 9,000 - 10,000 cpm
- 10,000 - 20,000 cpm
- > 20,000

1 inch = 140 feet

1:1,680

N W E S

140 70 0 140 Feet

CR1-E STATIC GAMMA SCAN

Prepared For: U.S. EPA Region 9

Prepared By:

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Task Order No.:	Contract No.:
0003	EP-S9-17-03
Location:	**Date:**
NAVAJO NATION	9/13/2021

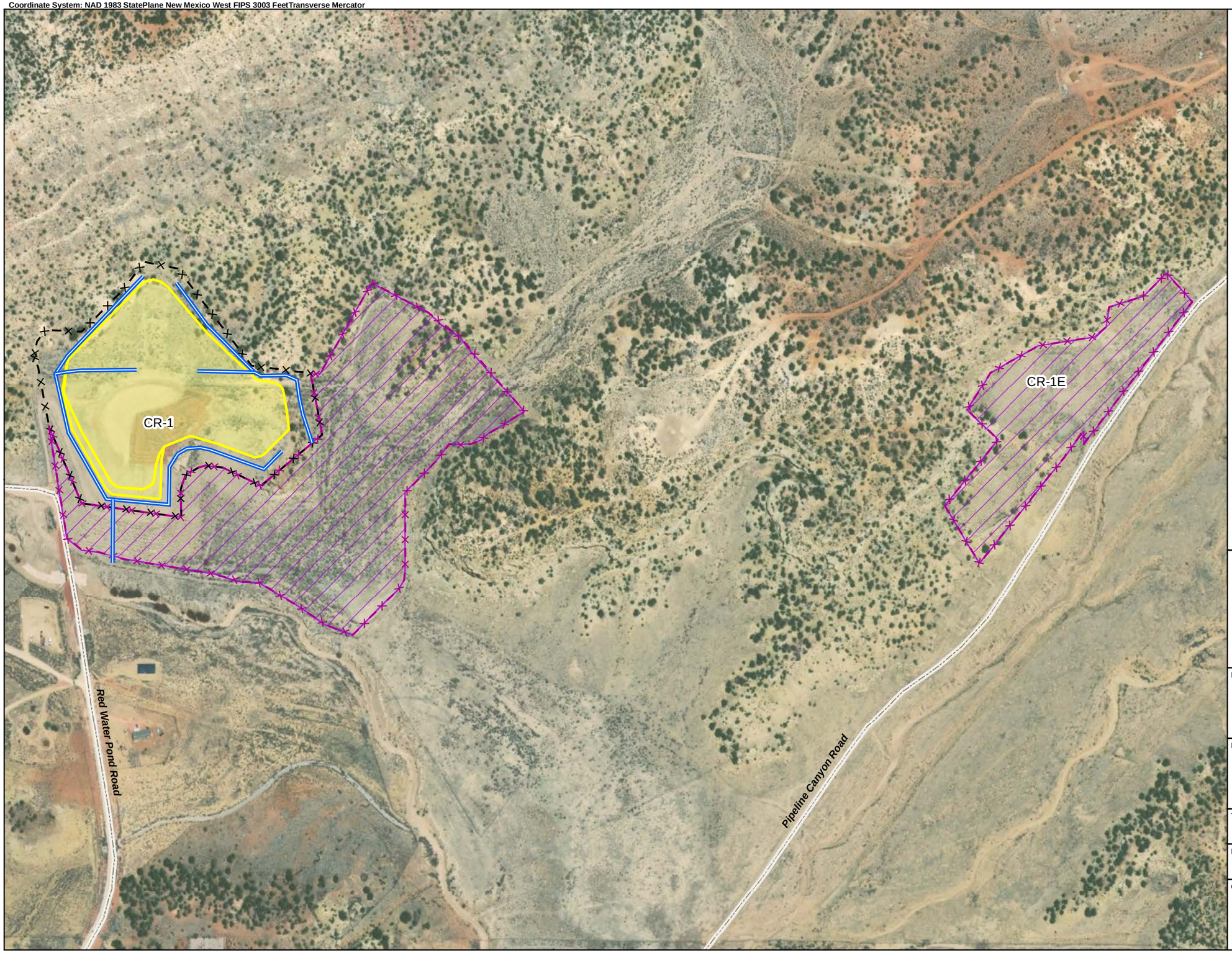
Coordinate System:

NAD 1983 State Plane New Mexico West
FIPS 3003 Feet Transverse Mercator

Figure No.:

13

Coordinate System: NAD 1983 StatePlane New Mexico West FIPS 3003 FeetTransverse Mercator



- Repository Cover
- Restoration Area
- Drainage Channel
- Repository Fence
- Temporary Fence
- Access Route

1 in = 400 feet

1:4,800

N
W E
S

400 200 0 400 Feet

ALTERNATIVE 2
CONCEPTUAL LAYOUT

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Task Order No.:	Contract No.:
TO0003	EP-S9-17-03
Location: NAVAJO NATION	Date: 10/19/2020
Coordinate System: NAD 1983 State Plane New Mexico West FIPS 3003 Feet Transverse Mercator	Figure No.: 14

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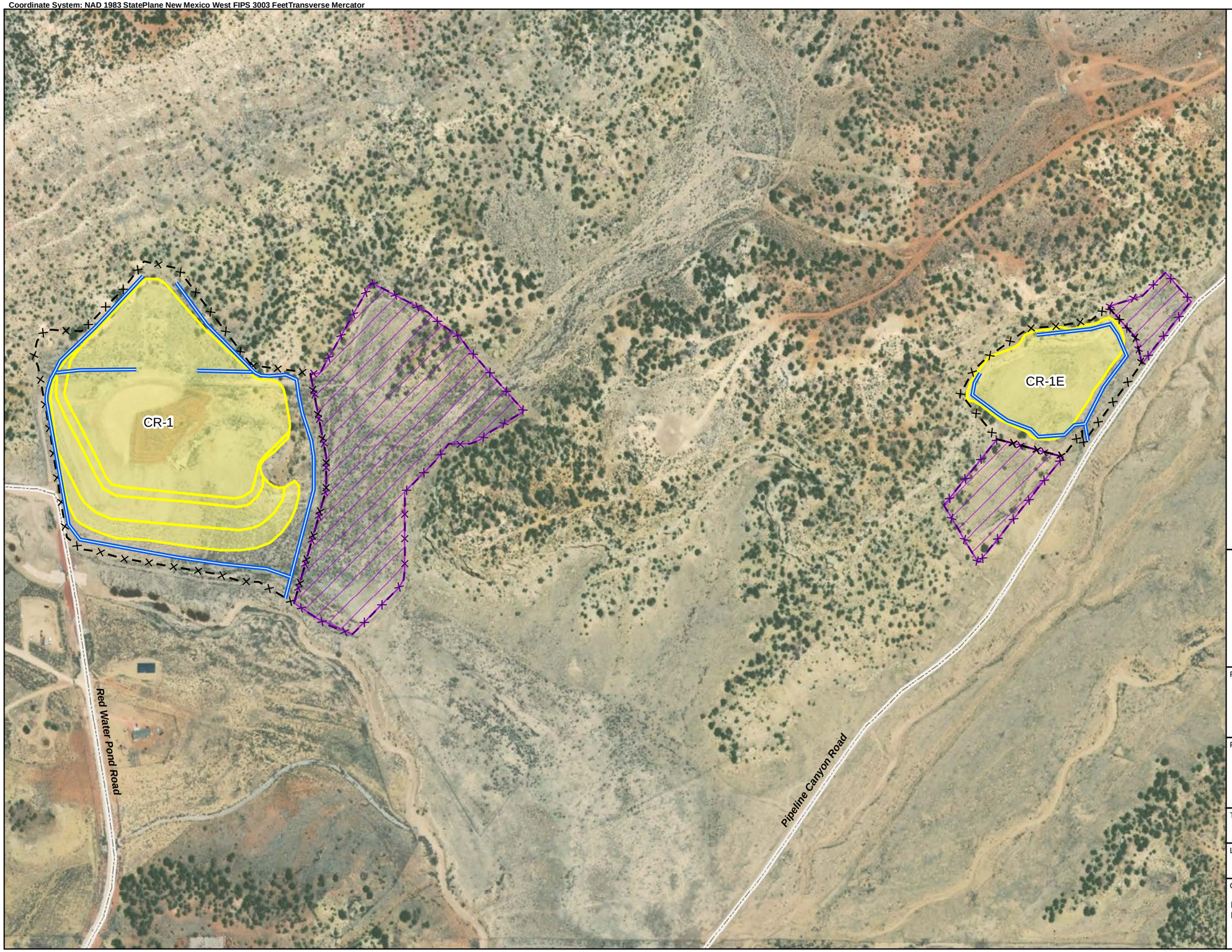
Coordinate System: NAD 1983 StatePlane New Mexico West FIPS 3003 FeetTransverse Mercator



- Repository Cover
- Restoration Area
- Drainage Channel
- Repository Fence
- Temporary Fence
- Access Route

1 in = 400 feet

1:4,800

N
W E
S

400 200 0 400 Feet

ALTERNATIVE 3
CONCEPTUAL LAYOUT

Prepared For: U.S. EPA Region 9

Prepared By:

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Task Order No.:	Contract No.:
TO0003	EP-S9-17-03
Location: COYOTE CANYON CHAPTER NAVAJO NATION	Date: 10/19/2020
Coordinate System: NAD 1983 State Plane New Mexico West FIPS 3003 Feet Transverse Mercator	Figure No.: 15

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TABLES

Table 1. Summary of Analytical Results
Quivira Tronox Mine Site, Navajo Nation, New Mexico

Location	Depth	Number of Samples	Range of Detected Radium-226 Concentrations	
			Minimum (pCi/g)	Maximum (pCi/g)
Quivira CR-1				
Quivira CR-1 Waste Rock Area	0-24 inch	26	1.24	154
	30-36 inch	10	2.25	189
	deep drilling 5-60 feet	42	2.96	110
Quivira CR-1 Former Pond Area	0-24 inch	43	1.05	47.1
	30-36 inch	21	0.89	29.2
	deep drilling 1.5-30 feet	172	0.9	472
Quivira CR-1 Former Industrial Area	0-24 inch	18	0.98	7.37
	30-36 inch	7	0.84	4.71
	deep drilling 1.5-13.5 feet	14	0.67	14.2
Quivira CR-1 Step Out Area	0-24 inch	10	1.04	30.2
	30-36 inch	1	--	1.25
Quivira CR-1E				
Quivira CR-1E Lease Area	0-24 inch	31	1.18	363
	30-36 inch	9	1.13	151
	deep drilling waste rock, 5-25 feet	10	1.01	206
	deep drilling former industrial and former pond ,1.5-13.5 feet	20	1.03	476
Quivira CR-1E Step Out Area	0-24 inch	7	1.2	60.4
	30-36 inch	2	2.39	2.9
Quivira Unnamed Arroyo #2 Area	0-6 inch	26	0.703	2.54
	30-36 inch	11	1.03	2.66
Quivira Pipeline Canyon Arroyo	0-6 inch	14	0.9	1.81
	30-36 inch	4	1.13	2.66
Quivira Vent Hole 4 -- may be removed and consolidated at Quivira CR-1				
Radium-226 (pCi/g)	0-2 feet	35	0.672	91.8
Radium-228 (pCi/g)	0-2 feet	35	0.504	1.92

Notes:

[a] Cancer risk calculated using the USEPA's default residential scenario PRG (https://epa-prgs.ornl.gov/cgi-bin/radionuclides/rprg_search) for radium-226+D and radium-228+D at the 10^{-6} risk level, including the soil ingestion, inhalation, external exposure and produce consumption pathways. Note that the default residential scenario does not consider the consumption of meat. Concentrations also include background contribution (mean background concentration is 1 pCi/g [MWH, 2006]).

HHRA = human health risk assessment

pCi/g = picoCuries per gram

PRG = Preliminary Remediation Goal

SL = screening level

USEPA = United States Environmental Protection Agency

* multiplication for the risk estimate. Conc/screen level times 1e-6

Table 2. Estimated Surface Areas and Waste Volumes
Quivira Tronox Mine Site, Navajo Nation, New Mexico

Name	Surface Area (square feet)	Surface Area (acres)	Waste Volume (cubic yards)
Quivira CR-1 Waste Areas			
Waste Rock and Former Ponds 1-3			685,959
Former Industrial Area North			20,137
Former Industrial Area Central			8,874
Former Industrial Area East			6,405
Former Pond 4,5			42,298
Former Pond 6			20,037
Step-Out Areas			21,501
Other CR-1 Areas			5,000
Quivira CR-1 Subtotal	**1,772,892**	**40.7**	**810,211**
Quivira CR-1E Waste Areas			
Waste Rock and Former Pond			72,508
Former Industrial Area North			10,785
Former Industrial Area South			1,195
Step-Out Areas			18,639
Quivira CR-1E Subtotal	**561,924**	**12.9**	**103,127**
Kerr McGee Ponds			
Ponds Area			127,500
Kerr McGee Ponds Subtotal	**431,244**	**9.9**	**127,500**
TOTAL	**2,766,060**	**63.5**	**1,040,838**

Table 3. Potential Federal and Tribal Chemical-Specific ARARs

Citation	Requirement	Prerequisite	Preliminary ARAR Determination	Comments
FEDERAL				
SOIL				
No potential chemical-specific ARARs are identified for metals or radionuclides or radioactivity in soil and waste rock at the Quivira Mines. Preliminary removal action goals are risk-based goals and not ARAR-based standards.				
AIR				
Uranium Mill Tailings Radiation Control Act				
40 CFR § 192.02(b)	Control of residual radioactive materials and their listed constituents must be designed to assure that the release of radon-222 to the atmosphere does (1) not exceed an average (over the entire surface of the disposal site and over at least a 1-year period) of 20 pCi/m^2-sec; or (2) not increase the annual average concentration of radon-222 in air at or above any location outside the disposal site by more than 0.5 pCi/L.	UMTRCA Title I Site	Relevant and appropriate	These standards are applicable to UMTRCA Title I Sites. The Quivira Mines site is not a Title I site; therefore, these requirements are not applicable. These requirements have been determined to be relevant and appropriate to the design of repository to be constructed in Alternatives 2 or 3, which consists of a disposal site for the contaminated soil and uranium waste rock.

Table 3. Potential Federal and Tribal Chemical-Specific ARARs

Citation	Requirement	Prerequisite	Preliminary ARAR Determination	Comments
FEDERAL				
Clean Air Act				
40 CFR §§ 61.222(a) and 61.223(a)	Radon-222 emissions to the ambient air from a uranium mill tailings pile that is no longer operational shall not exceed 20 pCi/m^2-sec. Sixty days following completion of covering the pile to limit radon emissions, but prior to the long-term stabilization (defined as the addition of material on the pile for the purpose of ensuring compliance with the requirements of 40 CFR § 192.02[a]), testing shall be conducted in accordance with the procedures described in 40 CFR Part 61, Appendix B, Method 115	Non-operational uranium mill tailing disposal site	Relevant and appropriate	These requirements are applicable to non-operational uranium mill tailings piles. The Quivira Mines site does not contain uranium mill tailings and none of the waste to be disposed of in the repository in Alternative 2 or 3, is uranium mill tailings. These requirements have been determined to be relevant and appropriate to the repository, which consists of a disposal site for the contaminated soil and uranium waste rock. Sixty days following completion of covering the pile to limit radon emission, but prior to long-term stabilization, testing must be completed.
TRIBAL				
No potential chemical-specific tribal ARARs are identified for metals or radionuclides or radioactivity in soil or in air emissions. Preliminary removal action goals are risk-based goals and not ARAR-based standards.				

Notes:

§	Section
ARAR	Applicable or relevant and appropriate requirement
CFR	Code of Federal Regulations
pCi/L	Picocurie per liter
pCi/m^2-sec	Picocurie per square meter per second
UMTRCA	Uranium Mill Tailings Radiation Control Act

Table 4. Potential Federal and Tribal Location-Specific ARARs

Citation	Requirement	Prerequisite	Preliminary ARAR Determination	Comments
FEDERAL				
BIOLOGICAL RESOURCES				
Endangered Species Act				
16 U.S.C. §§ 1536(a)(2) and 1538 50 CFR § 17.11, 17.21, and 17.31(a)	Federal agencies may not carry out actions that jeopardize the continued existence of any listed species. It is unlawful to take a threatened or endangered species or cause the destruction or modification of critical habitat.	Presence of a threatened or endangered species	Applicable	No ecological resource evaluations have been completed specifically for CR-1, CR-1E, or the Kerr McGee Ponds. The EIS for nearby NECR described 13 federal-, state-, and Navajo-listed animal species known to inhabit the area as well as three plant species of concern. Biological surveys will be completed prior to on-site construction of the repositories under Alternatives 2 and 3 to assess whether any threatened or endangered species are present and would be affected by the removal action. If so, USEPA will collaborate with the U.S. Fish and Wildlife Service to develop appropriate avoidance measures and habitat restoration requirements.
CULTURAL RESOURCES				
National Historic Preservation Act				
54 U.S.C. §§ 30610, 306102, 306107, and 306108 36 CFR Part 800	Federal agencies are required to protect historic properties and to take into account the effect of their actions on historic properties. Federal agencies must consult with the THPO to determine whether proposed federal actions	Property included on or eligible for the National Register of Historic Places	Applicable	Cultural resource surveys completed during field investigations in 2010 did not identify any culturally significant resources at the Quivira Mines. Other areas may be disturbed in the construction of new access roads and other actions evaluated in the removal action alternatives. These areas would require evaluation for the presence of culturally significant resources. If found, USEPA would work with Navajo Nation THPO to determine if the resources would be adversely affected.

Table 4. Potential Federal and Tribal Location-Specific ARARs

Citation	Requirement	Prerequisite	Preliminary ARAR Determination	Comments
FEDERAL				
	will have an adverse effect on historic properties and to identify alternatives or modifications to the proposed action to avoid, minimize, or mitigate adverse effects.			
Preservation of Historical and Archaeological Data Act				
54 U.S.C. §§ 312502 and 312503	When federal agency action may cause irreparable loss or destruction of significant scientific, prehistorical, historical, or archaeological data, the federal agency may request the Secretary of the Interior recover, protect, and preserve the data requested.	Federal agency action that would cause irreparable loss to significant historic or archaeological data	Applicable	Cultural resource surveys completed during field investigations in 2010 did not identify any culturally significant resources at the Quivira Mines. Other areas may be disturbed in the construction of new access roads and other actions evaluated in the removal action alternatives. These areas would require evaluation for the presence of significant historic or archaeological data. If found, USEPA would work with THPO to determine necessary preservation actions.
Native American Graves Protection and Repatriation Act				
25 U.S.C. §§ 3001-3013 43 CFR §§ 10.4, 10.5, 10.6, and 10.7	When human remains, funerary objects, sacred objects, or objects of cultural patrimony on federal or tribal lands are discovered on tribal land, the responsible tribe must be notified, activity	Excavation on federal or tribal land	Applicable	Cultural resource surveys completed during field investigations in 2010 did not identify any culturally significant resources at the Quivira Mines. Other areas may be disturbed in the construction of new access roads and other actions evaluated in the removal action alternatives. These areas would require evaluation for the presence of remains of objects or archaeological data. If found during the survey or during

Table 4. Potential Federal and Tribal Location-Specific ARARs

Citation	Requirement	Prerequisite	Preliminary ARAR Determination	Comments
FEDERAL				
	in the area must stop, and consultation with the tribe must be initiated to determine proper ownership and custody.			earth moving activity, USEPA would work with THPO to determine proper ownership and custody.

Citation	Requirement	Prerequisite	Preliminary ARAR Determination	Comments
TRIBAL				
BIOLOGICAL RESOURCES				
Navajo Nation Endangered Species Act (ESA)				
Navajo Nation Code, Title 4, Chapter 3, Subchapter 21 § 507(A) and (C)	It is unlawful for anyone to take, possess, transport, export, process, sell, offer for sale, or ship any species appearing on any of the following lists: (1) the list of endangered species developed by the Navajo Nation Council; or (2) U.S. threatened or endangered species list.	A species on the Navajo Nation Council list or on the U.S. threatened or endangered species list	Applicable	No ecological resource evaluations have been completed specifically for CR-1, CR-1E, or the Kerr McGee Ponds. The EIS for nearby NECR described 13 federal-, state-, and Navajo-listed animal species known to inhabit the area as well as three plant species of concern. The Navajo Nation ESA is identified as a potential tribal ARAR to the extent that it presents requirements that are more stringent than those in the federal ESA. If any threatened or endangered species are determined to be present and would be affected by the removal action, USEPA will collaborate with Navajo Nation to determine if the Navajo Nation ESA presents requirements for avoidance and habitat restoration that are more stringent than those in the federal ESA.

Table 4. Potential Federal and Tribal Location-Specific ARARs

Citation	Requirement	Prerequisite	Preliminary ARAR Determination	Comments
TRIBAL				
Navajo Nation Cultural Resources Protection Act				
Navajo Nation Code, Title 19, Chapter 11 § 1021	The sponsor of any undertaking on Navajo land must obtain the approval of the Preservation Officer prior to implementation of the undertaking to ensure protection of cultural resources.	Undertaking on Navajo lands	Applicable	Cultural resource surveys completed during field investigations in 2010 did not identify any culturally significant resources in the Quivira Mines. Other areas may be disturbed in the construction of new access roads and other actions evaluated in the removal action alternatives. These areas would require evaluation for the presence of cultural resources. If found during the survey or during earth moving activity, USEPA would work with THPO to determine appropriate protection measures.

Notes:

§	Section
ARAR	Applicable or relevant and appropriate requirement
CFR	Code of Federal Regulations
ERA	Ecological risk assessment
ESA	Endangered Species Act
THPO	Tribal Historic Preservation Office
U.S.C.	United States Code
USEPA	U.S. Environmental Protection Agency

Table 5. Potential Federal and Tribal Action-Specific ARARs

Action	Alternatives	Citation	Summary of Requirement	Prerequisite	Preliminary ARAR Determination	Comments
FEDERAL						
Clean Water Act						
Excavation at the mine sites and construct, repair, and remove haul/access roads	2, 3, 4	33 U.S.C. § 1342(p)(3)(A) 40 CFR § 122.44(k)(2)	Construction activity that affects 1 acre or more must use best management practices to control stormwater discharge	Construction activity that affects 1 acre or more	Applicable	For all alternatives, the excavation and the construction, repair, and removal of the haul/access roads will affect more than 1 acre. Best management practices would be used to the extent practicable considering the site-specific factors, including the steep slopes.
Uranium Mill Tailings Radiation Control Act						
Construction of repository at CR-1 or CR-1E	2, 3	40 CFR § 192.02(a)	The design for the control of residual radioactive materials must be effective for up to 1,000 years to the extent reasonably achievable and, in any case, for at least 200 years	UMTRCA Title I uranium mill site	Relevant and appropriate	For Alternatives 2 and 3, the UMTRCA design standard is not applicable to the repository. However, the requirement is identified as relevant and appropriate because the repository will control residual radioactive materials similar to an UMTRCA disposal site and the requirements will be considered to the extent practicable.

Table 5. Potential Federal and Tribal Action-Specific ARARs

Action	Alternatives	Citation	Summary of Requirement	Prerequisite	Preliminary ARAR Determination	Comments
FEDERAL						
Construction of repository at CR-1 or CR-1E	2, 3	40 CFR § 192.02(d)	The uranium mill tailings disposal site must be designed and stabilized in a manner that minimizes the need for future maintenance	UMTRCA Title 1 uranium mill site	Relevant and appropriate	The UMTRCA standard is not applicable to the repository. However, the requirement is identified as relevant and appropriate because the repository will control residual radioactive materials.
Atomic Energy Act						
Construction of repository at CR-1 or CR-1E	2, 3	10 CFR Part 40, Appendix A, Criterion 1	Uranium mill tailings disposal site selection criteria, including (1) remoteness; (2) natural conditions that contribute to continued immobilization and isolation of contaminants from groundwater sources; (3) potential for minimizing erosion, disturbance, and dispersion by natural forces; and (4) disposed in a manner that no active maintenance is required to preserve site conditions	NRC-licensed uranium mill tailings disposal site	Relevant and appropriate	For Alternatives 2 and 3, these requirements are not applicable to the repository. However, the requirements are identified as relevant and appropriate because the repository will control residual radioactive materials.
Construction of repository at CR-1 or CR-1E	2, 3	10 CFR Part 40, Appendix A, Criterion 4	Uranium mill tailings disposal site design criteria, including (1) topographic features	NRC-licensed uranium mill tailings disposal site	Relevant and appropriate	These requirements are not applicable to the repository. However, the requirements are identified as relevant and

Table 5. Potential Federal and Tribal Action-Specific ARARs

Action	Alternatives	Citation	Summary of Requirement	Prerequisite	Preliminary ARAR Determination	Comments
FEDERAL						
			that provide good wind protection; (2) relatively flat cover slopes to minimize erosion; (3) full self-sustaining vegetative or rock cover to reduce wind and water erosion; (4) located away from a fault that could cause a maximum credible earthquake larger than what the impoundment could reasonably withstand; and (5) incorporate features that promote deposition where feasible.			appropriate because the will control residual radioactive materials.
Construction of repository at CR-1 or CR-1E	2, 3	10 CFR Part 40, Appendix A, Criterion 6(1)	Tailings must be covered by an earthen cover or approved appropriate alternative that (1) provides reasonable assurance of control of radiological hazards; (2) is effective for 1,000 years to the extent reasonably achievable and for at least 200 years; and (3) limits the release of	NRC-licensed uranium mill tailings disposal site	Relevant and appropriate	These requirements are not applicable to the repository. However, the requirements are identified as relevant and appropriate because the repository will control residual radioactive materials. Two different types of covers, including an earthen cover, are evaluated for the closure of the repository. All the covers would achieve the radon-222 emission standard (not to

Table 5. Potential Federal and Tribal Action-Specific ARARs

Action	Alternatives	Citation	Summary of Requirement	Prerequisite	Preliminary ARAR Determination	Comments
FEDERAL						
			radon-222 to the atmosphere so as not to exceed an average release rate of 20 pCi/m^2-sec to the extent practicable throughout the effective design life. Excess moisture in soil may not be considered; direct gamma exposure should be reduced to background; the effects of any thin synthetic layer may not be taken into account in calculating radon exhalation level; and non-soil covers must be demonstrated to not crack or degrade by differential settlement, weathering, or other mechanism.			exceed 20 pCi/m^2-sec) in this criterion and in the potential chemical-specific ARARs.
Construction of repository at CR-1 or CR-1E	2,3	10 CFR Part 40, Appendix A, Criterion 6(3)	When the final radon barrier is placed in phases, verification of the radon-222 release rate must be completed for each portion of the final radon barrier as it is emplaced	NRC-licensed uranium mill tailings disposal site	Relevant and appropriate	These requirements are not applicable to the repository. However, the requirements are identified as relevant and appropriate because the repository will control residual radioactive materials. Construction may occur over

Table 5. Potential Federal and Tribal Action-Specific ARARs

Action	Alternatives	Citation	Summary of Requirement	Prerequisite	Preliminary ARAR Determination	Comments
FEDERAL						
						more than one season. If it does, the radon barrier will be tested when placed.
Construction of repository at CR-1 or CR-1E	2,3	10 CFR Part 40, Appendix A, Criterion 6(5)	Prohibiting near-surface materials from including waste or rock that contains elevated levels of radium, requiring that soils used for near-surface cover be essentially the same as far as radioactivity is concerned	NRC-licensed uranium mill tailings disposal site	Relevant and appropriate	These requirements are not applicable to the repository. However, the requirement is identified as relevant and appropriate because the repository will contain residual radioactive materials. Soil cover material will be obtained from nearby borrow sources.
Construction of repository at CR-1 or CR-1E	2,3	10 CFR Part 40, Appendix A, Criterion 6(7)	Disposal sites must be closed in a manner that minimizes the need for further maintenance and, to the extent necessary, to control, minimize, or eliminate post-closure escape of non-radiological hazardous constituents, leachate, contaminated rainwater, or waste decomposition products to the ground or surface waters or atmosphere	NRC-licensed uranium mill tailings disposal site	Relevant and appropriate	These requirements are not applicable to the repository. However, the requirements are identified as relevant and appropriate because the repository will contain residual radioactive materials. The containment of the radionuclides will also adequately contain the metals to prevent escape to other environmental media.

Table 5. Potential Federal and Tribal Action-Specific ARARs

Action	Alternatives	Citation	Summary of Requirement	Prerequisite	Preliminary ARAR Determination	Comments
TRIBAL						
Close, stabilize, or repair adits	2, 3, 4	Navajo Nation Code, Title 18, Chapter 15 § 1639(A)	Open and abandoned tunnels, shafts, and entryways from previous mining operations may be sealed to prevent public health or safety hazards	Open and abandoned tunnels, shafts, or entryway declared by the Director to be a hazard to public health or safety	Relevant and appropriate	In 1988, the Navajo Nation received approval for its NAMLRP. Therefore, NAMLRP requirements were reviewed as potential ARARs instead of the requirements in the federal SMCRA. This provision is not applicable to closing, stabilizing, or repairing adits as part of the removal action. However, this is identified as relevant and appropriate to closing the adits to prevent access to the mines.

Notes:

§	Section
ARAR	Applicable or relevant and appropriate requirement
CFR	Code of Federal Regulations
NAMLRP	Navajo Abandoned Mine Land Reclamation Program
NRC	Nuclear Regulatory Commission
pCi/m^2-sec	picocuries per square meter per second
SMCRA	Surface Mine Control and Reclamation Act
UMTRCA	Uranium Mill Tailings Radiation Control Act
U.S.C.	United States Code

Table 6. Surficial Restoration Approach Matrix for Tronox Quivira Mines

		Access Controls		Construction BMPs				Road Erosion Controls		Drainage Erosion Controls		Steep Slope Erosion Controls			Common Erosion Controls			
Restoration Areas	**Surficial Restoration Type**	**Fencing/ Road Barriers**	**Portal Closure**	**Contouring and Inward Grading For Drainage**	**Benching/ Laying Back Steep Slopes and Highwalls**	**Pulling Overbank Material onto Road Cut**	**Grading Drainage for Energy Grade Line**	**Water Control Bars**	**Rock Crossings/ Culverts**	**Gabion Weir**	**Rocks/ Boulders/ Structures for Energy Dissipation**	**Gabion Wall**	**Articulated Concrete Matting**	**Shotcrete**	**Diverting Water Using Berms/ Ditches**	**Sediment Detention Basin/ Infiltration Gallery**	**Revegetation (Planting/ Seeding)**	**Blankets, Wattles, Coir Logs**
Roads	Access																	
	Paved																	
Waste Rock at CR-1 and CR-1E	Excavated Areas on Shallow Slopes																	
	Excavated Areas on Steep Slopes																	
Kerr McGee Ponds	Excavated Areas on Shallow Slopes																	

Notes:

BMP	Best management practice
	Green shading means a restoration approach is applicable for a site area
	Yellow shading means a restoration approach is potentially applicable for a site area
	No shading means a restoration approach is not applicable for a site area

Table 7. Alternative Comparative Analysis for Quivira Mine Sites

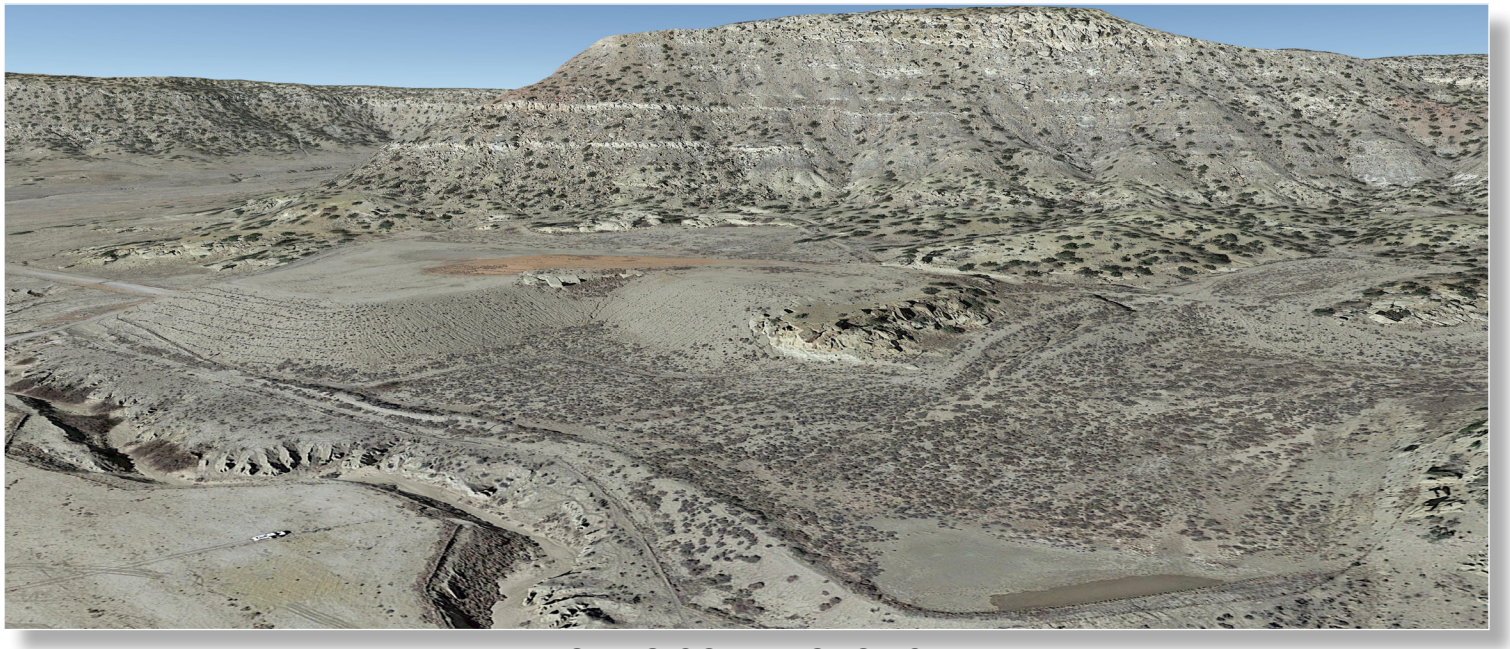
Alternative		Threshold Criteria		Effectiveness		Implementability		Cost
		Protective of Human Health and the Environment	Compliance with ARARs	Short-Term (during Action)	Long-Term (after Action)	Technical Feasibility/ Availability of Services and Materials	Administrative Feasibility	$ (Million Dollars)
1	No Further Action	Fail	Fail	Very Good	Very Poor	Very Good	Very Good	Very Good $0
2	Consolidate and Cover on Site at CR-1	Pass	Pass	Good	Good	Good	Good	Good $41.1
3	Consolidate and Cover on Site at CR-1 and CR-1E	Pass	Pass	Good	Good	Good	Average	Average $46.6
4	Disposal at White Mesa Mill	Pass	Pass	Poor	Very Good	Good	Good	Poor $276.3
	Disposal at Off-Navajo Nation Clean Harbors Hazardous Waste Disposal Facility	Pass	Pass	Very Poor	Very Good	Very Good	Good	Very Poor $550.6

Note:
ARAR Applicable or relevant and appropriate requirement

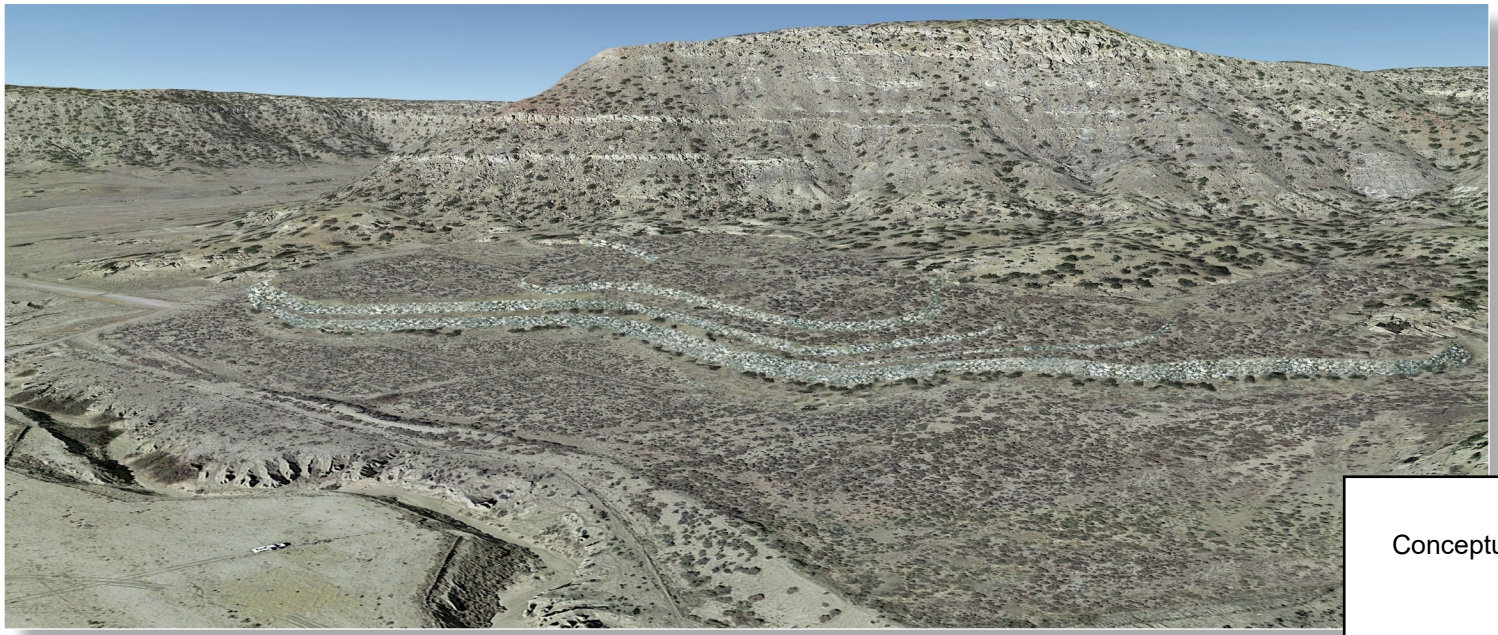
APPENDIX A
SITE IMAGES

(NOT INCLUDED IN DRAFT)

APPENDIX B
POST-REMOVAL VISUALIZATIONS



EXISTING CONDITIONS - CR-1



PROPOSED RECLAMATION - CR-1

Conceptual CR-1 Repository Post Removal Action

TETRA TECH

EXISTING CONDITIONS - CR-1E

PROPOSED RECLAMATION - CR-1E

Conceptual CR-1E Repository
Post Removal Action

TETRA TECH

APPENDIX C
COST ANALYSIS

Table C-1 - Alternative 2A - Cap Waste at Quivira CR-1

Cost Estimate Summary

Site: Quivira Tronox Mine Site
Location: Navajo Nation, New Mexico
Phase: Feasibility Study (-30% to +50%)
Base Year: 2020
Date: November, 2020

Description: Alternative 4A consists of consolidation and capping of mine waste from CR-1E and other areas at CR-1.

Direct Capital Costs

Description	Quantity	Unit	Unit Cost	Total Cost
Field Overhead and Oversight Costs:				
Field Overhead and Oversight	17.0	Months	36,715.18	$624,200
Mobilization/Demobilization	6.0	Each	29,076.57	$174,500
Travel, Lodging and Per Diem	255.0	Ea Person per MO	4,995.00	$1,273,700
Voluntary Alternative Housing	1.0	Lump Sum	2,000,000.00	$2,000,000
SUBTOTAL				**$4,072,000**
General Site Work Costs:				
Fence Construction/Repair - Equipment Storage Area	1,000	LF	$28.24	$28,200
Clearing and Grubbing	64	AC	$1,331.54	$85,100
Land Surveying	64	AC	$697.34	$44,600
SUBTOTAL				**$158,000**
Earthwork Costs:				
Excavation of Mine Waste (excavate and load onto trucks)	314,463	BCY	$1.77	$556,600
Excavation of Mine Waste - Dozer (Assuming 25% of total volume)	78,616	BCY	$4.41	$346,700
General Backfill from Off-Site	98,325	LCY	$30.69	$3,017,900
General Backfill from On-Site	229,425	LCY	$15.49	$3,554,700
On-Site Transportation	345,237	LCY	$7.27	$2,509,900
Transporting Waste from CR-1E to CR-1	38,274	LCY	$6.66	$254,903
Site Restoration	38	AC	$21,512.08	$815,300
Erosion and Sediment Control	192	AC-YR	$735.10	$140,900
Dust Control	317	Day	$5,930.88	$1,881,700
Unnamed Arroyo #2 Sloping and Armoring	1	Lump Sum	$191,749.50	$191,700
Pipeline Arroyo Sloping, Armoring, and Road Rebuilding	1	Lump Sum	$293,147.53	$293,100
Soil Cap	247,500	CCY	$34.10	$8,440,700
Rock Armoring on Benches	10,352	LCY	$139.02	$1,439,100
Mirafi 160N/O Orange Nonwoven Fabric	74,453	SY	$1.81	$134,800
SUBTOTAL				**$23,578,000**
Transportation and Disposal Costs:				
Off-Site Disposal of Contaminated Soil	0	Ton	$0.00	$0
SUBTOTAL				**$0**
Total Direct Capital Costs (Rounded to Nearest $1,000)				**$27,808,000**

Indirect Capital Costs

Description	%			Total Cost
Permitting/Planning/Institutional Controls	4%			$1,112,320
Professional/Tech. - Project Management	5%			$1,390,400
Professional/Tech. - Remedial Design	6%			$1,668,480
Professional/Tech. - Construction Mgmt.	6%			$1,668,480
Total Indirect Capital Costs (Rounded to Nearest $1,000)				**$5,840,000**

Total Capital Costs

Description	%			Total Cost
Subtotal Capital Costs				$33,648,000
Contingency Allowance	15%			$5,047,200
Total Capital Cost (Rounded to Nearest $1,000)				**$38,695,200**

O&M Costs

Description				Total Cost
Annual O&M costs include Regrading and Revegentation				
Present Worth of 30 Years O&M (Rounded to the Nearest $1,000)	**3.5%**			$1,924,526
Contingency Allowance (25%)	**25%**			$481,132
Total Present Worth O&M Cost (Rounded to Nearest $1,000)				**$2,406,000**
Total Cost (Rounded to Nearest $1,000)				**$41,101,000**

Notes:

x1.25 Expansion Factor Used for all LCY quantities

x0.9 Compaction Factor Used for all CCY quantities

X1.5 Expansion Factor Used for Hauling of Building Demolition Waste

A Breakdown of Quantities Can be Found in Tables 1-6a and 1-6b

BCY	Bank Cubic Yards
CCY	Compacted Cubic Yards
CF	Cubic Feet
EA	Each
HDPE	High-density Polyethylene
LCY	Loose Cubic Yards
LF	Linear Feet
P/A	Present Value Given Annual Cost
P/F	Present Value Given Future Cost
SF	Square Foot
SY	Square Yards

Table C-2 - Alternative 2B - Cap Waste at Quivira CR-1 with Top Liner

Cost Estimate Summary

Site: Quivira Tronox Mine Site
Location: Navajo Nation, New Mexico
Phase: Feasibility Study (-30% to +50%)
Base Year: 2020
Date: November, 2020

Description: Alternative 4B consists of consolidation and capping of mine waste from CR-1E and other areas at CR-1 with a top liner.

Direct Capital Costs

Description	Quantity	Unit	Unit Cost	Total Cost
Field Overhead and Oversight Costs:				
Field Overhead and Oversight	17.0	Months	36,715.18	$624,200
Mobilization/Demobilization	6.0	Each	29,076.57	$174,500
Travel, Lodging and Per Diem	255.0	Ea Person per MO	4,995.00	$1,273,700
Voluntary Alternative Housing	1.0	Lump Sum	2,000,000.00	$2,000,000
SUBTOTAL				**$4,072,000**
General Site Work Costs:				
Fence Construction/Repair - Equipment Storage Area	1,000	LF	$28.24	$28,200
Clearing and Grubbing	64	AC	$1,331.54	$85,100
Land Surveying	64	AC	$697.34	$44,600
SUBTOTAL				**$158,000**
Earthwork Costs:				
Excavation of Mine Waste (excavate and load onto trucks)	314,463	BCY	$1.77	$556,600
Excavation of Mine Waste - Dozer (Assuming 25% of total volume)	78,616	BCY	$4.41	$346,700
General Backfill from Off-Site	98,325	LCY	$30.69	$3,017,900
General Backfill from On-Site	229,425	LCY	$15.49	$3,554,700
On-Site Transportation	345,237	LCY	$7.27	$2,509,900
Transporting Waste from CR-1E to CR-1	38,274	LCY	$6.66	$254,900
Site Restoration	38	AC	$21,512.08	$815,300
Erosion and Sediment Control	192	AC-YR	$735.10	$140,900
Dust Control	317	Day	$5,930.88	$1,881,700
Unnamed Arroyo #2 Sloping and Armoring	1	Lump Sum	$191,749.50	$191,700
Pipeline Arroyo Sloping, Armoring, and Road Rebuilding	1	Lump Sum	$293,147.53	$293,100
Top Liner	670,077	SF	$1.00	$670,077
Soil Cap	247,500	CCY	$34.10	$8,440,700
Rock Armoring on Benches	10,352	LCY	$139.02	$1,439,100
SUBTOTAL				**$24,113,000**
Transportation and Disposal Costs:				
Off-Site Disposal of Contaminated Soil	0	Ton	$0.00	$0
SUBTOTAL				**$0**
Total Direct Capital Costs (Rounded to Nearest $1,000)				**$28,343,000**

Indirect Capital Costs

Description	%			Total Cost
Permitting/Planning/Institutional Controls	4%			$1,133,720
Professional/Tech. - Project Management	5%			$1,417,150
Professional/Tech. - Remedial Design	6%			$1,700,580
Professional/Tech. - Construction Mgmt.	6%			$1,700,580
Total Indirect Capital Costs (Rounded to Nearest $1,000)				**$5,952,000**

Total Capital Costs

Description	%			Total Cost
Subtotal Capital Costs				$34,295,000
Contingency Allowance	15%			$5,144,250
Total Capital Cost (Rounded to Nearest $1,000)				**$39,439,250**

O&M Costs

Description				Total Cost
Annual O&M costs include Regrading and Revegentation				
Present Worth of 1000 Years O&M (Rounded to the Nearest $1,000)	**3.5%**			$1,924,526
Contingency Allowance (25%)	**25%**			$481,132
Total Present Worth O&M Cost (Rounded to Nearest $1,000)				**$2,406,000**
Total Cost (Rounded to Nearest $1,000)				**$41,845,000**

Notes:

x1.25 Expansion Factor Used for all LCY quantities

x0.9 Compaction Factor Used for all CCY quantities

X1.5 Expansion Factor Used for Hauling of Building Demolition Waste

A Breakdown of Quantities Can be Found in Tables 1-6a and 1-6b

BCY	Bank Cubic Yards
CCY	Compacted Cubic Yards
CF	Cubic Feet
EA	Each
HDPE	High-density Polyethylene
LCY	Loose Cubic Yards
LF	Linear Feet
P/A	Present Value Given Annual Cost
P/F	Present Value Given Future Cost
SF	Square Foot
SY	Square Yards

Table C-3 - Alternative 3A - Cap Waste at Quivira CR-1 and Quivira CR-1E

Cost Estimate Summary

Site: Quivira Tronox Mine Site
Location: Navajo Nation, New Mexico
Phase: Feasibility Study (-30% to +50%)
Base Year: 2020
Date: November, 2020

Description: Alternative 3A consists of consolidation and capping of mine waste at CR-1 and CR-1E sites.

Direct Capital Costs

Description	Quantity	Unit	Unit Cost	Total Cost
Field Overhead and Oversight Costs:				
Field Overhead and Oversight	21.0	Months	36,715.18	$771,000
Mobilization/Demobilization	6.0	Each	29,076.57	$174,500
Travel, Lodging and Per Diem	315.0	Ea Person per MO	4,995.00	$1,573,400
Voluntary Alternative Housing	1.0	Lump Sum	2,000,000.00	$2,000,000
SUBTOTAL				**$4,519,000**
General Site Work Costs:				
Fence Construction/Repair - Equipment Storage Area	1,000	LF	$28.24	$28,200
Clearing and Grubbing	64	AC	$1,331.54	$85,100
Land Surveying	64	AC	$697.34	$44,600
SUBTOTAL				**$158,000**
Earthwork Costs:				
Excavation of Mine Waste (excavate and load onto trucks)	241,955	BCY	$1.77	$428,300
Excavation of Mine Waste - Dozer (Assuming 25% of total volume)	60,489	BCY	$4.41	$266,800
General Backfill from Off-Site	98,325	LCY	$30.69	$3,017,900
General Backfill from On-Site	229,425	LCY	$15.49	$3,554,700
On-Site Transportation	302,444	LCY	$7.27	$2,198,800
Site Restoration	30	AC	$21,512.08	$643,200
Erosion and Sediment Control	192	AC-YR	$735.10	$140,900
Dust Control	398	Day	$5,930.88	$2,359,300
Unnamed Arroyo #2 Sloping and Armoring	1	Lump Sum	$191,749.50	$191,700
Pipeline Arroyo Sloping, Armoring, and Road Rebuilding	1	Lump Sum	$293,147.53	$293,100
Soil Cap	328,500	CCY	$34.10	$11,203,100
Rock Armoring on Repository Benches	16,791	LCY	$139.02	$2,334,285
Mirafi 160N/O Orange Nonwoven Fabric	85,564	SY	$1.81	$154,900
SUBTOTAL				**$26,787,000**
Transportation and Disposal Costs:				
Off-Site Disposal of Contaminated Soil	0	Ton	$0.00	$0
SUBTOTAL				**$0**
Total Direct Capital Costs (Rounded to Nearest $1,000)				**$31,464,000**

Indirect Capital Costs

Description	%			Total Cost
Permitting/Planning/Institutional Controls	4%			$1,258,560
Professional/Tech. - Project Management	5%			$1,573,200
Professional/Tech. - Remedial Design	6%			$1,887,840
Professional/Tech. - Construction Mgmt.	6%			$1,887,840
Total Indirect Capital Costs (Rounded to Nearest $1,000)				**$6,607,000**

Total Capital Costs

Description	%			Total Cost
Subtotal Capital Costs				$38,071,000
Contingency Allowance	15%			$5,710,650
Total Capital Cost (Rounded to Nearest $1,000)				**$43,781,650**

O&M Costs

Description				Total Cost
Annual O&M costs include Regrading and Revegentation				
Present Worth of 1000 Years O&M (Rounded to the Nearest $1,000)	**3.5%**			$2,220,000
Contingency Allowance (25%)	**25%**			$555,000
Total Present Worth O&M Cost (Rounded to Nearest $1,000)				**$2,775,000**
Total Cost (Rounded to Nearest $1,000)				**$46,557,000**

Notes:

x1.25 Expansion Factor Used for all LCY quantities

x0.9 Compaction Factor Used for all CCY quantities

X1.5 Expansion Factor Used for Hauling of Building Demolition Waste

A Breakdown of Quantities Can be Found in Tables 1-6a and 1-6b

BCY	Bank Cubic Yards
CCY	Compacted Cubic Yards
CF	Cubic Feet
EA	Each
HDPE	High-density Polyethylene
LCY	Loose Cubic Yards
LF	Linear Feet
P/A	Present Value Given Annual Cost
P/F	Present Value Given Future Cost
SF	Square Foot
SY	Square Yards

Table C-4 - Alternative 3B - Cap Waste at Quivira CR-1 and Quivira CR-1E with Top Liner

Cost Estimate Summary

Site: Quivira Tronox Mine Site
Location: Navajo Nation, New Mexico
Phase: Feasibility Study (-30% to +50%)
Base Year: 2020
Date: November, 2020

Description: Alternative 3B consists of consolidation and capping of mine waste at CR-1 and CR-1E sites with a top liner.

Direct Capital Costs

Description	Quantity	Unit	Unit Cost	Total Cost
Field Overhead and Oversight Costs:				
Field Overhead and Oversight	21.0	Months	36,715.18	$771,000
Mobilization/Demobilization	6.0	Each	29,076.57	$174,500
Travel, Lodging and Per Diem	315.0	Ea Person per MO	4,995.00	$1,573,400
Voluntary Alternative Housing	1.0	Lump Sum	2,000,000.00	$2,000,000
SUBTOTAL				**$4,519,000**
General Site Work Costs:				
Fence Construction/Repair - Equipment Storage Area	1,000	LF	$28.24	$28,200
Clearing and Grubbing	64	AC	$1,331.54	$85,100
Land Surveying	64	AC	$697.34	$44,600
SUBTOTAL				**$158,000**
Earthwork Costs:				
Excavation of Mine Waste (excavate and load onto trucks)	241,955	BCY	$1.77	$428,300
Excavation of Mine Waste - Dozer (Assuming 25% of total volume)	60,489	BCY	$4.41	$266,800
General Backfill from Off-Site	98,325	LCY	$30.69	$3,017,900
General Backfill from On-Site	229,425	LCY	$15.49	$3,554,700
On-Site Transportation	302,444	LCY	$7.27	$2,198,800
Site Restoration	30	AC	$21,512.08	$643,200
Erosion and Sediment Control	192	AC-YR	$735.10	$140,900
Dust Control	398	Day	$5,930.88	$2,359,300
Unnamed Arroyo #2 Sloping and Armoring	1	Lump Sum	$191,749.50	$191,700
Pipeline Arroyo Sloping, Armoring, and Road Rebuilding	1	Lump Sum	$293,147.53	$293,100
Top Liner	770,077	SF	$1.00	$770,077
Soil Cap	328,500	CCY	$34.10	$11,203,100
Rock Armoring on Benches	16,791	LCY	$139.02	$2,334,300
SUBTOTAL				**$27,402,000**
Transportation and Disposal Costs:				
Off-Site Disposal of Contaminated Soil	0	Ton	$0.00	$0
SUBTOTAL				**$0**
Total Direct Capital Costs (Rounded to Nearest $1,000)				**$32,079,000**

Indirect Capital Costs

Description	%			Total Cost
Permitting/Planning/Institutional Controls	4%			$1,283,160
Professional/Tech. - Project Management	5%			$1,603,950
Professional/Tech. - Remedial Design	6%			$1,924,740
Professional/Tech. - Construction Mgmt.	6%			$1,924,740
Total Indirect Capital Costs (Rounded to Nearest $1,000)				**$6,737,000**

Total Capital Costs

Description	%			Total Cost
Subtotal Capital Costs				$38,816,000
Contingency Allowance	15%			$5,822,400
Total Capital Cost (Rounded to Nearest $1,000)				**$44,638,400**

O&M Costs

Description				Total Cost
Annual O&M costs include Regrading and Revegentation				
Present Worth of 1000 Years O&M (Rounded to the Nearest $1,000)	**3.5%**			$2,220,000
Contingency Allowance (25%)	**25%**			$555,000
Total Present Worth O&M Cost (Rounded to Nearest $1,000)				**$2,775,000**
Total Cost (Rounded to Nearest $1,000)				**$47,413,000**

Notes:

x1.25 Expansion Factor Used for all LCY quantities

x0.9 Compaction Factor Used for all CCY quantities

X1.5 Expansion Factor Used for Hauling of Building Demolition Waste

A Breakdown of Quantities Can be Found in Tables 1-6a and 1-6b

BCY	Bank Cubic Yards
CCY	Compacted Cubic Yards
CF	Cubic Feet
EA	Each
HDPE	High-density Polyethylene
LCY	Loose Cubic Yards
LF	Linear Feet
P/A	Present Value Given Annual Cost
P/F	Present Value Given Future Cost
SF	Square Foot
SY	Square Yards

Table C-5 - Alternative 4A - Dispose all Waste at a Licensed Facility

Cost Estimate Summary

Site: Quivira Tronox Mine Site
Location: Navajo Nation, New Mexico
Phase: Feasibility Study (-30% to +50%)
Base Year: 2020
Date: November, 2020

Description: Alternative 4A consists of removal, transportation, and disposal of mine waste at White Mesa Mill.

Direct Capital Costs

Description	Quantity	Unit	Unit Cost	Total Cost
Field Overhead and Oversight Costs:				
Field Overhead and Oversight	70.0	Months	36,715.18	$2,570,100
Mobilization/Demobilization	18.0	Each	29,076.57	$523,400
Travel, Lodging and Per Diem	1,050.0	Ea Person per MO	4,995.00	$5,244,800
Voluntary Alternative Housing	1.0	Lump Sum	2,000,000.00	$2,000,000
SUBTOTAL				**$10,338,000**
General Site Work Costs:				
Fence Construction/Repair - Equipment Storage Area	1,000	LF	$28.24	$28,200
Clearing and Grubbing	64	AC	$1,331.54	$85,100
Land Surveying	64	AC	$697.34	$44,600
SUBTOTAL				**$158,000**
Earthwork Costs:				
Excavation of Mine Waste (excavate and load onto trucks)	1,040,838	BCY	$1.77	$1,842,300
Excavation of Mine Waste - Dozer (Assuming 25% of total volume)	260,210	BCY	$4.41	$1,147,500
General Backfill from Off-Site	145,791	LCY	$30.69	$4,474,800
General Backfill from On-Site	340,178	LCY	$15.49	$5,270,700
Site Restoration	64	AC	$21,512.08	$1,374,600
Erosion and Sediment Control	575	AC-YR	$735.10	$422,800
Dust Control	29	Day	$5,930.88	$171,200
Pipeline Arroyo Sloping, Armoring, and Road Rebuilding	1	Lump Sum	$293,147.53	$293,148
SUBTOTAL				**$14,997,000**
Transportation and Disposal Costs:				
Hauling to White Mesa Mill	1,301,048	LCY	$60.00	$78,062,900
Disposal Contaminated Soil - White Mesa Mill	1,301,048	LCY	$81.00	$105,384,800
Dust Control	1,355	Day	$5,930.88	$8,037,900
SUBTOTAL				**$191,485,600**
Total Direct Capital Costs (Rounded to Nearest $1,000)				**$216,979,000**

Indirect Capital Costs

Description	%		Total Cost
Permitting/Planning/Institutional Controls	4%		$4,463,768
Professional/Tech. - Project Management	5%		$5,579,710
Professional/Tech. - Remedial Design	5%		$5,579,710
Professional/Tech. - Construction Mgmt.	6%		$6,695,652
Total Indirect Capital Costs (Rounded to Nearest $1,000)			**$22,319,000**

Total Capital Costs

Description	%		Total Cost
Subtotal Capital Costs			$239,298,000
Contingency Allowance	15%		$35,894,700
Total Capital Cost (Rounded to Nearest $1,000)			**$275,192,700**

O&M Costs

Description				Total Cost
Annual O&M costs include Regrading and Revegentation				
Present Worth of 1000 Years O&M (Rounded to the Nearest $1,000)	**3.5%**			$920,336
Contingency Allowance (25%)	**25%**			$230,084
Total Present Worth O&M Cost (Rounded to Nearest $1,000)				**$1,150,000**
Total Cost (Rounded to Nearest $1,000)				**$276,343,000**

Notes:

x1.25 Expansion Factor Used for all LCY quantities

x0.9 Compaction Factor Used for all CCY quantities

BCY	Bank Cubic Yards
CCY	Compacted Cubic Yards
CF	Cubic Feet
EA	Each
HDPE	High-density Polyethylene
LCY	Loose Cubic Yards
LF	Linear Feet
P/A	Present Value Given Annual Cost
P/F	Present Value Given Future Cost
SF	Square Foot
SY	Square Yards

Table C-6 - Alternative 4B - Dispose all Waste at a Licensed Facility

Cost Estimate Summary

Site: Quivira Tronox Mine Site
Location: Navajo Nation, New Mexico
Phase: Feasibility Study (-30% to +50%)
Base Year: 2020
Date: November, 2020

Description: Alternative 4B consists of removal, transportation, and disposal of mine waste at Deer Trail, CO Facility.

Direct Capital Costs

Description	Quantity	Unit	Unit Cost	Total Cost
Field Overhead and Oversight Costs:				
Field Overhead and Oversight	138.0	Months	36,715.18	$5,066,700
Mobilization/Demobilization	36.0	Each	29,076.57	$1,046,800
Travel, Lodging and Per Diem	2,070.0	Ea Person per MO	4,995.00	$10,339,700
Voluntary Alternative Housing	1.0	Lump Sum	2,000,000.00	$2,000,000
SUBTOTAL				**$18,453,000**
General Site Work Costs:				
Fence Construction/Repair - Equipment Storage Area	1,000	LF	$28.24	$28,200
Clearing and Grubbing	64	AC	$1,331.54	$85,100
Land Surveying	64	AC	$697.34	$44,600
SUBTOTAL				**$158,000**
Earthwork Costs:				
Excavation of Mine Waste (excavate and load onto trucks)	1,040,838	BCY	$1.77	$1,842,300
Excavation of Mine Waste - Dozer (Assuming 25% of total volume)	260,210	BCY	$4.41	$1,147,500
General Backfill from Off-Site	145,791	LCY	$30.69	$4,474,800
General Backfill from On-Site	340,178	LCY	$15.49	$5,270,700
Site Restoration	64	AC	$21,512.08	$1,374,600
Erosion and Sediment Control	1,150	AC-YR	$735.10	$845,500
Dust Control	29	Day	$5,930.88	$171,200
Pipeline Arroyo Sloping, Armoring, and Road Rebuilding	1	Lump Sum	$293,147.53	$293,148
SUBTOTAL				**$15,420,000**
Transportation and Disposal Costs:				
Hauling to Deer Trail, CO	1,301,048	LCY	$180.00	$234,188,600
Disposal Contaminated Soil - Deer Trail, CO	1,301,048	LCY	$105.00	$136,610,000
Dust Control	2,711	Day	$5,930.88	$16,075,700
SUBTOTAL				**$386,874,300**
Total Direct Capital Costs (Rounded to Nearest $1,000)				**$420,905,000**

Indirect Capital Costs

Description	%		Total Cost
Permitting/Planning/Institutional Controls	4%		$11,371,800
Professional/Tech. - Project Management	5%		$14,214,750
Professional/Tech. - Remedial Design	5%		$14,214,750
Professional/Tech. - Construction Mgmt.	6%		$17,057,700
Total Indirect Capital Costs (Rounded to Nearest $1,000)			**$56,859,000**

Total Capital Costs

Description	%		Total Cost
Subtotal Capital Costs			$477,764,000
Contingency Allowance	15%		$71,664,600
Total Capital Cost (Rounded to Nearest $1,000)			**$549,428,600**

O&M Costs

Description			Total Cost
Annual O&M costs include Regrading and Revegentation			
Present Worth of 1000 Years O&M (Rounded to the Nearest $1,000)	**3.5%**		$920,336
Contingency Allowance (25%)	**25%**		$230,084
Total Present Worth O&M Cost (Rounded to Nearest $1,000)			**$1,150,000**
Total Cost (Rounded to Nearest $1,000)			**$550,579,000**

Notes:

x1.25 Expansion Factor Used for all LCY quantities

x0.9 Compaction Factor Used for all CCY quantities

BCY	Bank Cubic Yards
CCY	Compacted Cubic Yards
CF	Cubic Feet
EA	Each
HDPE	High-density Polyethylene
LCY	Loose Cubic Yards
LF	Linear Feet
P/A	Present Value Given Annual Cost
P/F	Present Value Given Future Cost
SF	Square Foot
SY	Square Yards

APPENDIX D
GREENER CLEANUP ANALYSIS

(NOT INCLUDED IN DRAFT)